NBSIR 73-263

Fire Endurance Tests of Unprotected Wood-Floor Constructions for Single-Family Residences

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Center for Building Technology
Institute for Applied Technology
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Final Report

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ABSTRACT

Fire endurance tests were performed on two full-scale and twelve small scale wood floor constructions. The fire endurance ratings on unfinished wood joist and plywood subfloor constructions varied from 10 to 13 minutes and were mainly determined by the time to "flame through." In small-scale tests, the addition of carpeting with a hair pad delayed the time of "flame through" approximately 8 minutes. Time to "flame through" may be estimated from the thermal resistance of the construction, and may be modified by the effects of applied load or construction details such as gaps, joints, and penetrations.

Key Words: Fire endurance; fire test; flame through; full scale; housing; Operation BREAKTHROUGH; single family residence; small scale; thermal resistance; wood floor; wood joist

TABLE OF CONTENTS

Page

1.0 INTRODUCTION

A series of fire tests were conducted to measure the fire endurance of wood floor constructions representiative of those used in single family residences. The fire exposure followed the requirements of the Standard Methods of Fire Tests of Building Constructions and Materials ASTM E 119-70 [1] 1/ for floors. Tests were run on both full-scale specimens (13-1/2 ft. by 18 ft.) with superimposed loads and on small-scale specimens (2 ft. by 2 ft. nominal) loaded with "dead" weight to restrain the specimens.

The assemblies tested included several plywood subflooring and underlayment combinations and strip flooring directly on 2 x 8 or 2 x 10 2/ wood joists. The effect of carpeting was also examined.

The fire endurance time was generally governed by excessive temperature rise on the unexposed surface of the wood floor. Failure by flame through (directly through the wood or at joints) as well as the inability to sustain the applied load followed shortly thereafter.

Small scale tests were also performed in a nominal 2 ft. x 2 ft. furnace to investigate a much wider range of constructions than could be tested full scale. To the extent that thermal effects principally determine fire behavior, it should be possible to predict the results of full scale tests from those of small scale tests.

1/ Numbers in brackets refer to reference given at the end of the report.

2/ All sizes of wood members in the test hereafter are given as nominal sizes in inches in accordance with SPR 16-53 [2].

In the full-scale tests, the fire endurance time was 11 min:38 sec by load failure for two layers of 1/2 in. plywood with or without carpeting (2 x 10 joists at 16 in. centers), and 9 minutes by temperature failure for a single layer 1/2 in. square edge plywood with blocked joints, and 10 minutes by temperature failure for a single layer of 5/8 in. plywood with tongue and groove joints (2 x 8 joists at 16 in. centers).

In the small scale tests covering 12 different constructions, fire endurance ranged from 9 min:30 sec to 25 min:50 sec.

2.0 PREPARATION OF TEST SPECIMENS

2.1 Construction of Full Scale Test Specimens

2.1.1 Specimen of Test #L-1

The assembly was built into the 18 ft. x 13 ft.-6 in. framed opening of the National Bureau of Standards (NBS) Floor Test Furnace. The specimen consisted of air dried 2 x 10 construction grade Douglas Fir joists spaced at 16 in. on center on a span of 13 ft.-6 in. Solid 2 x 10 bridging of the joists was spaced 5 feet apart and was staggered for direct nailing. Flooring material, as shown in figure 1, consisted of 1/2 in. thick grade C-D plywood subfloor and 1/2 in. grade A-C plywood underlayment. The plywood grades indicated here were in conformance with U.S. Product Standard, PS 1-66. The subfloor was nailed with 8d coated nails spaced 6 in. on center along the edges and 10 in. along the intermediate joists, starting with a full sheet in the NW corner. Underlayment was nailed with 6d coated nails spaced at 12 in. on center starting with a full sheet in the SE corner to provide a pattern of staggered joints between layers. Though the nailing was not strictly in accordance with the FHA Minimum Property Standards (MPS)[3], it is commonly used in the house construction.

In conformance with general practice and according to FHA-MPS requirements, a 1/16 in. spacing was allowed at the plywood joints.

The perimeter of the specimen was simply supported along the edges of the furnace. Gypsum board protection was provided along the edges.

As shown in figure 1, one half of the specimen was covered with nylon 501 carpet (weight 66.7 oz/yd^2), while the other half, designated as "bare", had no finish floor. Figure 2 shows the underside of the floor, including joists and solid bridging, furnace thermocouples, observation windows, and gas burners. Figure 3 is a general sketch of the large floor test furnace.

The lumber used for the joists was Rocky Mountain Region Douglas Fir which has an allowable stress level of 1050 pounds per square inch (psi) in bending. A load of 63.7 lbs/ft^2, calculated to produce a working stress of 1050 psi in bending at the extreme fibers of the joists, was applied to the floor through four hydraulic jacks.

2.1.2 Specimen of Test #L-2

The size of the floor and the layout of the joists were the same as in test #L-1 except that 2 x 8 joists were used instead of 2 x 10's and steel automatic adjustable bridging was used along the longitudinal centerline instead of solid wood bridging.

Two types of combined subfloor-underlayment construction were used. The floor was equally divided into two parts along the east-west center line as shown in figure 4. One area consisted of a layer of 1/2 in. thick plywood (interior A-C grade with exterior glue) with a square edge joints protected by 2 x 3 blocking placed in line for toe nailing. The other area consisted of a layer of 5/8 in. thick plywood tongue and groove joints at all edges (underlayment grade, sand finished, with exterior glue). The floor was nailed with 8d common nails spaced 10 in. on center.

In this test the applied load was reduced to a nominal 20 psf (21 psf actual) to study the effect of a more representative live load. This load, which was applied to the floor by the method used in test #L-1, represented approximately 38 percent of the working stress of the joists (see Appendix II).

The typical moisture content of each material, based on a measured weight loss at 105°C was (a) 10% for 5/8 in. thick tongue and groove plywood, (b) 6% for 1/2 in. plywood, (c) 12% for 2 x 8 joist.

2.2 Instrumentation-Full Scale Test

2.2.1 Test #L-1

The instrumentation consisted of thermocouples, floor deflection indicators, smoke meters and a motion picture camera. Eighteen Chromel-Alumel (type K, .020 in. diameter wire) thermocouples were placed on the top (unexposed surface) of the floor under 0.4 in. thick 6 x 6 in. felted asbestos pads in such a way as to avoid contact with the steel loading apparatus. In addition, five thermocouples were located under the carpet at the quarter points and at the center of the carpeted area. The distribution of the thermocouples is shown in figure 1.

The temperatures of all the thermocouples were printed out at 2 minute intervals on a Data Logger and then converted to punched cards for graphing by a Calcomp Plotter.

Smoke meters with a 16 in. optical path were used to measure the density of smoke accumulating above the two floor sections. They were placed on the carpet 59 in. from the west edge and 28 in. from the east-west centerline in the carpeted area and approximately at the diagonal opposite side over the bare area. The smoke meter consisted of a sheet metal canopy to collect the smoke arranged with a light source on one side and a vacuum phototube on the other side. An opening was provided at the bottom for air inlet and holes were provided in the top for the controlled discharge of the smoky air.

The deflection indicators consisted of wires attached to nails placed at three points; at the quarter points and midway along the north-south centerline (see figure 1). The wires were terminated with small weights which kept them taut. Indicating riders were attached to the wires where they passed over a vertical scale just above the small weights. Each rider indicated the amount of movement at the corresponding point on the floor during the test.

2.2.2 Test #L-2

The instrumentation was essentially the same as in the test #L-1, except no smoke measurements were made. The location of the thermocouples is shown in figure 5.

2.3 Construction and Instrumentation-Small Scale Test Specimens

Twelve (#S-1 through #S-12) small scale tests were performed on 2 ft. x 2 ft. nominal (25 in. x 25 in. actual) specimens constructed of 2 x 10 joists spaced 16 in. on centers with various combinations of flooring material. Specimen configuration is shown in figure 6 and the constructions and loadings are summarized in Table 1, Appendix I. Joints of the underlayment and subfloor were perpendicular and met at the midpoint. In tests #S-1 and #S-2 a 1/16 in. spacing was allowed at the plywood joints as in the large scale tests. Since it was not possible to apply enough load on the small scale specimen to produce the equivalent stress levels as on the large scale specimen, in tests #S-3, #S-4, #S-6, #S-7, #S-8 and

#S-10 the plywood joint spacing was set at 1/8 in. This simulated more closely the cracks observed in the plywood during the large-scale test due to the applied load. Joist and end blocking details are shown in figure 6.

Thermocouples were placed in the following manner: 1 thermocouple at mid-depth of the center, 2 thermocouples on the unexposed wood surface and, where applicable, there were 2 thermocouples on the rug. When the joint was protected with a 2 x 4 or 2 x 3 blocking as shown in figure 7 the thermocouple at the center was moved to the top of the blocking.

3.0 TEST PROCEDURE

3.1 Full Scale Test

Load was applied eight minutes prior to the start of test with 35 steel channels, 5 in. x 24 in, which approximated a uniform load. Details of the allowable live load calculation based on full design stress are given in Appendix II.

The average temperature inside the furnace was measured by twelve protected thermocouples and was made to follow the standard ASTM E119-70 temperature-time curve by automatic control of the gas flow to the burners, which is shown in figure 8.

3.2 Small Scale Test

Test specimen #S-1 was not loaded during the fire test. A load of 40 lbs. (10 psf) was applied to specimen #S-2 at two locations by setting weights 4 in. each side of the longitudinal centerline. The load was increased from 40 lbs. to 240 lbs. by putting four 60 lbs. weights at four locations in Test #S-3 through Test #S-12 as shown in figure 9.

Four protected thermocouples were used to measure the average temperature inside the furnace which was made to follow the ASTM Standard E119-70 temperature-time curve by automatic control of the gas flow to the burner.

3.3 Fire Endurance Criteria

The fire endurance of a construction defined by the criteria of failure designated by ASTM E119-70 is as follows:

(a) The construction shall have sustained the applied load during the fire endurance test without passage of flame or gases hot enough to ignite cotton waste, for a period equal to that for which classification is desired.

(b) Transmission of heat through the construction during the fire endurance test shall not raise the average temperature on its unexposed surface more than 250°F (139°C) or 325°F (181°C) at one point, above its initial temperature.

4.0 TEST RESULTS

4.1 General Observations of Full Scale Test

A log of observation made during the test is given in Appendix III.

4.1.1 Test #L-1

Flame penetration near the center at the joint between the two sheets of plywood in the upper layer of the "bare" floor was observed at 13 min: 30 sec. The location where flaming occurred and the associated charred region is shown in figure 10. There was also a load failure, as evidenced by the inability to maintain hydraulic pressure at 11 min:38 sec.

The average temperature rise of the surface thermocouples on the "bare" floor was less than 75°C when the test was terminated after 15 minutes. A single thermocouple on the carpet exceeded a 50°C rise, with a reading of 80°C indicating that it may have been directly over a nailhead. The average temperatures of the "bare" floor and the carpet-finished floor are shown along with the average temperature beneath the carpet in figure 11.

The smoke meter on the "bare" floor showed a sudden increase in smoke at about 9 minutes, which was more than 4 minutes before "flame through" was noticed. The smoke level indicated by the meter over the carpet-finished floor was considerably less. Smoke meter transmission is given in Table 2, Appendix I and figure 12.

The deflection increased steadily to 6.5 in. at 11 min:38 sec when the load could not be maintained as shown in figure 13. Deflections are tabulated in Table 3, Appendix I.

There was a few small scorch marks on the hair pad due to heat conduction through the nails. This continued into the burlap backing of the nylon carpet at several locations leaving scorch spots up to 1 inch in diameter.

4.1.2 Test #L-2

Flames penetrated the 1/2 in. plywood floor near the quarter point along the longitudinal centerline between the blocked joints at 11 min. Flames were noticed along the tongue and groove joint near the center on the southwest side about 50 seconds later.

Figure 14 illustrates average temperature rises on the unexposed surface. Temperature failure occurred at 9 min. for the 1/2 in. plywood floor and 10 min. for the 5/8 in. plywood floor.

Figure 15 is the temperature history of six specially arranged thermocouples (see figure 5). The slow rise in temperature of thermocouple C illustrates the effectiveness of the blocking in protecting the joint.

The deflections are tabulated in Table 4, Appendix I and shown graphically in figure 16. The deflection increased rapidly and the floor broke through at 13 min.

4.2 General Observations of Small Scale Tests

A log of observations made during the test is given in Appendix III.

4.2.1 Test #S-1

Some difficulty with the furnace control was experienced at the beginning of this test causing the furnace temperature-time curve to be below the standard temperature-time curve (see figure 17). Flame through occurred at 21 min:43 sec. The corrected time of flame through, according to the correction formula stated in ASTM E119-70 based on the comparison of the areas under the actual time-temperature curve and the standard curve, was 18 min:10 sec.

The corrected time to flame through was 5 minutes longer than in the full scale test. The probable reason for this difference was that no load was applied to produce downward bending and opening of the joints. During the test the center part of the joint tended to bend upward due to thermal stress.

4.2.2 Test #S-2

The flame through occurred at 17 min:21 sec. This compares quite well with the corresponding time of 18 min:10 sec in test #S-1 considering that a light load of 10 psf was applied in test #S-2. No bending was observed either upward or downward throughout this test.

4.2.3 Test #S-3

The time 12 min:45 sec. to reach flame through was considerably decreased compared to test #S-2. As indicated in the test observations, it took about four minutes to produce a definite flame through after the subfloor burned out in test #S-2 but only one half a minute in test #S-3. The flame through was primarily through the 1/8 in. joint separation provided in the construction.

The applied load did not appear to unduly influence the behavior of the specimen. This load, however, was used as a standard condition for the remaining small scale tests.

The location of flame through was rather localized along the joint in test #S-3, compared to previous tests, as shown in Figure 18.

4.2.4 Test #S-4

The flame through region covered a large portion of the floor and originated in the same area as in test #S-3. In test #S-4 the fire burned a large hole all at once. The unexposed surface of the carpeted floor charred over a large area during the last 3 min:50 sec of test and then surface ignition suddenly took place over the char region at 25 min: 50 sec of test time. This was taken as the flame through time. Deflection due to the load was observed near the center after 21 min of test time.

4.2.5 Test #S-5

The tongue and groove joint started to char and open up at 9 min followed by flame through near the north quarter point at 10 min:30 sec of test time (see figure 19).

4.2.6 Test #S-6

The flame through (surface ignition) region was situated at the quarter points, i.e., directly through the plywood and carpeting, not at the joint.

The 2 x 4 blocking, besides protecting the joint thermally also acted like a stiffening beam and changed the pattern of the deflection and the flame through from that in test #S-4. Figures 20, 21 and 22 show the pattern of deflection at 17 min:30 sec and the flame through at 18 min:15 sec near the north quarter point and the flaming regions before extinguishment, respectively.

4.2.7 Test #S-7

The flame through occurred at 9 min:25 sec near the north quarter point, not at the protected joint, as in Test #S-6. However, the flame through occurred earlier since there was no carpet to provide additional thermal resistance.

4.2.8 Test #S-8

Deflection and charring near the center of the carpeted unexposed surface was observed at 17 min and 19 min:10 sec, respectively. The flame through (surface ignition) occurred near the center at 24 min in the same manner and location as in test #S-4.

4.2.9 Test #S-9

The tongue and groove joint started to char and open up near the center at 6 min. The flame through occurred near the center at 11 min: 35 sec.

4.2.10 Test #S-10

The flame through occurred at 11 min:35 sec near the north-south quarter areas and not at the protected joint. The pattern of the deflection and the flame through was similar to test #S-6.

4.2.11 Test #S-11

Deflection and charring on the unexposed surface of the carpeted floor was observed at 15 min of test time. The flame through (surface ignition) took place over a large portion of the floor at 19 min:20 sec.

4.2.12 Test #S-12

During construction of the specimen #S-12 a small piece (1 in. long) of tongue and groove was broken at the north end joint. Sagging and charring occurred at the joint with the broken tongue at 10 min:30 sec which is 1 min earlier than at the undamaged joints.

The flame through at the joint with the broken tongue and at an undamaged joint near the center occurred at 13 min:21 sec and 14 min:10 sec, respectively.

4.2.13 Temperature Readings on Small Scale Tests

Figures 23 and 24 show the temperature changes at half depth for the small scale tests. In figure 24 the slope of curve 7 is flatter than the others, which is explained by the blocking under the joint protecting the joint from the fire.

The temperature changes on the bare floor and on the carpet surface are shown in Figures 25, 26 and 27. The temperature failure due to the average temperature rise of 139°C on the unexposed surface occurred a few minutes (1-7 minutes) earlier than the failure by flame through. These are shown in Table 1 of Appendix I.

5.0 SUMMARY OF RESULTS

5.1 Comparison of the Results from the Full Scale and Small Scale Tests

Experiments were carried out to measure the time of fire endurance of the different floor constructions subjected to the conditions of the standard fire endurance test, ASTM E 119-70.

In loaded full-scale fire tests on unprotected wood floors, structural failure generally occurs at approximately the same time as excessive temperature rise or "flame through". In test #L-1 under the load, which produced the design stress (63.7 psf live) on the 2 x 10 joists, the load failure by inability to sustain the applied load occurred at 11 min: 38 sec and "flame through" at 13 min:30 sec. It was not possible to continue the test to achieve failure due to excessive temperature rise on the unexposed surface. To obtain a better measurement of temperature transmission failure, and to simulate a more representative floor live load, in test #L-2 with 2 x 8 joists the load was reduced to 20 psf. Load failure occurred at 13 min, temperature failure occurred between 9 and 10 minutes, and flame through occurred between 11 and 12 minutes.

It is believed that, as the supporting joists in the full scale test are destroyed by charring, cracks form at the highly stressed extreme fibers on the bottom surface. This increases the deflection and accelerates the rate of flame penetration through increased joint separations.

As previously mentioned in test #S-3, the 1/8 in. fixed gap on the underlayment joint reduced the time of "flame through" by 4.5 minutes. For both the large scale and small scale test, the temperature rise on the unexposed surface was nearly the same. It may be that the gap built in during construction of the small scale test specimen #S-3 corresponded to the cracks made on the exposed surface due to the load in the full scale test #L-1.

It is noticed that the time of flame through of the small scale tests on the 5/8 in. plywood with tongue and groove joint (Test #S-9) or the 1/2 in. plywood with square edge joint protected with 2 x 3 blocking (Test #S-10) are in agreement with those of the full scale test (Test #L-2).

Considering the criterion of temperature failure, it is interesting that the temperature failures occurred a few minutes earlier than the "flame through" failures in most cases. Table 1 of Appendix I summarizes the different types of failure on the various constructions, the loading conditions and the total thermal resistance.

Thermal resistance is calculated from the thickness and coefficient of thermal conductivity as follows:

$$\text{Thermal Resistance} = \frac{\text{Thickness}}{\text{Coefficient of Thermal Conductivity}}$$

The thermal properties which form the basis for the computed thermal resistance (see Table 5 of Appendix I) were obtained from a standard reference source.[4]

5.2 Effect of Carpeting

In the small scale tests (#S-4, -6 and -8), it was obvious that the carpeting delayed the time of "flame through" and temperature failure by 8 to 12 minutes. In the large scale test (Test #L-1), the carpet itself did not add any strength to the floor as evidenced by the slight difference in the deflections between the floor sections with or without carpet (see figure 13).

5.3 Estimation of the Time of "Flame Through"

Figure 28 illustrates the influence of the thermal conductivity of various materials on the time of "flame through" under free convection conditions and at room temperature. It is apparent that construction #S-4 (1/2 in. plywood + 1/2 in. plywood + 1/8 in. gap + carpet) has the largest value of thermal resistance and requires the longest time for the flame to penetrate through the floor. It can be also seen in figure 28, that empirically there is a linear relation between the thermal resistance and the "flame through" time. The developed slope K is 0.133 (BTU/°F).

For instance, a 1/8 in. vinyl asbestos tile will add a thermal resistance (R) of 0.05 (HR °F/BTU) to the floor. The additional time for the flame to pass through the tile with a resistance of R = 0.05 (HR °F/BTU) will be 24 seconds. The flame through time of 11 minutes was observed by experiment on 1/2 in. plywood with 2 x 3 blocking (test #L-2 and #S-10). Thus, the total time required for "flame through" on the floor construction of 1/2 in. plywood with 2 x 3 blocking, finished with 1/8 in. vinyl asbestos tile can be estimated as 11 min:24 sec.

6.0 CONCLUSION

Bare wood floor constructions conforming to the FHA Minimum Property Standards are able to meet a fire endurance time requirement of 10 minutes measured according to the ASTM E-119 Standard. This includes single-floor plywood constructions 1/2 in. and 5/8 in. thick. Strip flooring (25/32 in. softwood and 13/16 in. hardwood) directly over joists have a fire endurance time in the range of 10 to 13 minutes.

The addition of a separate finish floor should increase the fire endurance time by an amount dependent on its additional thermal resistance. This is estimated to be approximately 1/2 minute for 1/8 in. vinyl asbestos tile to approximately 10 minutes for carpeting over a hair pad.

For example, the time of flame through for the (1/2 in. plywood + 1/2 in. plywood + 1/8 in. gap + carpet) construction, which has total thermal resistance of 2.40 (HR °F/BTU), is almost 4 times that for the (1/2 in. plywood + 2 x 4 blocking) construction with total thermal resistance of 0.62 (HR °F/BTU).

The total thermal resistance of the floor construction can be used as a factor for estimation of "flame through" time. Further study would be necessary to determine the effects of the applied load or the gap size.

REFERENCES

1. Standard Methods of Fire Tests of Building Construction and Materials American Society for Testing and Materials Designation E119-70.

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3. Minimum Property Standards For One and Two Living Units, FHA No. 300, U.S. Department of HUD, FHA, Rev. January 1970.

4. "Handbook of Fundamentals, Heating, Refrigerating, Ventilating and Air Conditioning" Published by ASHRAE, 1967.

TEST	CONSTRUCTION	SMALL SCALE (2'x2') LOAD LB/ft²	FLAME THRU (MIN)	LOAD FAIL. (MIN)	TEMP.FAIL. (MIN)	FULL SCALE (13 1/2'x18') LOAD LB/ft²	FLAME THRU (MIN)	LOAD FAIL.* (MIN)	TEMP.FAIL. (MIN)	THERMAL RESISTANCE HR°F/BTU
1	1/2"+1/2"+1/16" gap (plywood)	None	21:43	---	17:10	---	---	---	---	1.25
2	1/2"+1/2"+1/16 gap (plywood)	10	17:21	---	----	63.7	13:30	11:38	>15:00	1.25
3	1/2"+1/2"+1/8" gap (plywood)	60	12:45	---	---	---	---	---	---	1.25
4	1/2"+1/2"+1/8" gap + carpet (plywood)	60	25:50	---	20:00	63.7	not reached	11:38	not reached	2.48
5	25/32" with T & G (pinewood)	60	10:30	---	---	---	---	---	---	0.98
6	1/2"+2"x4" Blocking + 1/8" gap and carpet (plywood)	60	18:15	---	11:30	---	---	---	---	1.85
7	1/2"+2"x4" Blocking + 1/8" gap (plywood)	60	9:25	---	8:00	---	---	---	---	0.62
8	1/2"+1/4"+1/8" gap & carpet (plywood)	60	24:00	---	22:30	---	---	---	---	2.16
9	5/8" with T & G (plywood)	60	11:35	---	10:24	21	11:50	13:00	10:00	0.78
10	1/2"+2"x4" Blocking + 1/16" gap (for #L-2) or 1/8" gap (for #S-10) (plywood)	60	11:00	---	6:30	21	11:00	13:00	9:00	0.62
11	5/8" with T & G & carpet (plywood)	60	19:20	---	17:15	---	---	---	---	2.01
12	13/16" with T & G (oak)	60	14:10	---	13:00	---	---	---	---	0.56

* Unable to maintain load application.

APPENDIX I
TABLE 1

FIRE ENDURANCE TIMES FOR VARIOUS FLOOR CONSTRUCTIONS

COMPARING SMALL AND FULL SCALE TEST

Table 2

TEST #L-1 SMOKE DEVELOPMENT

Time min:sec	Over Plywood T(%)	Over Plywood O.D	Over Carpet T(%)	Over Carpet O.D
0:00	100	0	100	0
1:00	99.5	0	100	0
2:00	99.5	0	99	0
3:00	96	0.01	96.5	0.01
4:00	97.5	0.01	97.5	0.01
5:00	97	0.01	95.5	0.01
6:00	97.5	0.01	97.5	0.01
7:00	93.5	0.037	91.5	0.04
8:00	88	0.053	89	0.053
9:00	78	0.01	86.5	0.06
10:00	11.2	0.93	80.5	0.09
11:00	4.5	1.35	78	0.1
12:00	12.4	0.9	72	0.2
12:30	Readings discontinued			

T(%): Measured transmission percentage from smoke meter

O.D: Optical density converted from T(%)

Table 3

TEST #L-1 DEFLECTION MEASUREMENTS

Measurements of deflections were made at three points on the longitudinal center line; at the North (N) and South (S) quarter points, and at dead center (C). Readings in inches.

	N	C	S
Before load	0	0	0
After load	0.18	0.20	0.20
min:sec.			
1:00	0.20	0.20	0.20
2:30	0.45	0.50	0.20
5:00	0.6	0.75	0.6
6:00	0.6	0.95	0.7
7:00	0.9	1.25	0.9
8:00	1.1	1.6	1.1
9:00	1.5	2.3	1.5
10:00	1.8	3.0	1.8
10:30	2.1	3.6	2.1
11:10	2.4	4.5	2.8
11:38	2.7	6.5	3.3

Load off (unable to maintain pressure)

Table 4

TEST #L-2 DEFLECTION MEASUREMENTS
(Reading in inches)

Time min:sec.	N	C	S
0:00	0	1	0.5
1:00	0	1.25	1.0
2:00	0	1.5	1.25
3:00	0	2	1.5
4:00	1	2.5	2
5:05	2.5	5	3.5
7:00	4	8	5
10:00	4	14	9
12:00	7	18	12
13:00	Wire broke	19	

Table 5

THERMAL RESISTANCE OF VARIOUS FLOOR MATERIAL [4]

MATERIAL	DENSITY LB/FT^3	CONDUCTIVITY BTU/HR FT °F K	CONDUCTANCE BTU/HR °F c	THICKNESS INCH L	THERMAL RESISTANCE HR °F/BTU R
Oak	51.5	1.2		13/16	0.65
Pine	34	0.8		25/32	0.98
Plywood		.80		1/2	0.62
Carpet plus hair pad			.8		1.2
Vinyl asbestos tile			20.0	1/8	0.05

$$R = \frac{L}{K} = 1/c$$

APPENDIX II

Live Load Calculations

Allowable design stress for Douglas fir construction grade joist with 2 x 10 and 2 x 8 in. cross-section on full scale test.

According to the stress equations

$$f_b = \frac{M}{I/C} \qquad [1]$$

and

$$M = \frac{WL^2}{8} \qquad [2]$$

Allowable bending stress

$$f_b = 1050 \text{ psi}$$

Section modulus

$$I/C = 24.44\ (in^3) \text{ for } 2 \times 10 \text{ joist}$$

$$I/C = 15.23\ (in^3) \text{ for } 2 \times 8 \text{ joist}$$

From Equation [1]

$$M_{2 \times 10} = 1050 \times 24.44 = 25{,}700\ (lb\text{-}in) = 2140\ (lb\text{-}ft)$$

From Equation [2]

$$W_{2 \times 10} = \frac{8\ \ (2140)}{(13.52)^2} = 94.0\ (lb/ft)$$

Above value is for unit length on the joist. Therefore, the working load corresponding to unit area can be converted by multiplying by the factor (12/16).

$$W_{2 \times 10} = 94.0 \times 12/16 = 70.5\ (psf)$$

Live load = Total allowable load - Dead load

Dead load = carpet	1.0 psf
Two layers of plywood (1" thick)	3.0 psf
+ joist (2 x 10 cross-section)	2.8 psf
total dead load	6.8 psf

therefore,

Live load/2 x 10 = 70.5 - 6.8 = 63.7 (psf)

Same manner

$W_{2 \times 8} = 58.3$ psf

Dead load = plywood (5/8 inch thick)

= 1.87 psf

therefore,

Live load/2 x 8 = 58.3 = 1.87 = 56.43 (psf)

NOMENCLATURE

M = Bending Moment

f_b = Bending Stress

I/C = Section Modulus

w = Load

c = Half depth of joist

Subscript 2 x 10 = 2 x 10 joist

Subscript 2 x 8 = 2 x 8 joist

APPENDIX III

Log of Observations During Test

Test #L-1

min:sec.	
1:00	Joist ignited, crackling sounds, smoke escaping between joists and plywood deck around the edge of the floor.
2:00	Fire-exposed plywood surfaces all scorched.
3:00	Inside of furnace filled with smoke and flame. Whole underside on fire.
4:00	West side of fire-exposed plywood burned more than east side.
5:00	Smoke increasing through the cracks at the perimeter, but no smoke directly from upper surface.
8:00	Crackling sounds were more severe.
10:00	Appreciable smoke around T/C #8 pad on bare floor.
11:38	"Load Failure" (could not sustain hydraulic load).
12:30	Load off. At least 2 joists were broken.
13:30	Flame through at joint.
15:00	Gas off. END OF TEST

Test #L-2

Time min:sec.	
0:40	Joist started flaming on the south side.
1:00	Joist started flaming on the north side.
1:30	Smoke on unexposed surface.
3:00	Large sheet of flames formed on under side of floor.
4:00	Formation of black char at a few spots on the top surface.
11:00	"Flame through" on 1/2 in. plywood floor.
11:50	"Flame through" on 5/8 in. plywood floor.
13:00	Load failure (floor broke through).

Test #S-1

6:45	Joists and exposed plywood surface ignited.
10:20	Tendency of center part of joint to bend upward due to thermal stress. Smoke coming out through joint.
18:00	Fire inside furnace seen through the opening of joint.
19:30	Small fire coming through the joint
20:00	Noticable difference in height between plywood sections at center of joint.
21:43	"Flame through."
(18:10)	(Corrected time for flame through, see General Observations of test #S-1).

Test #S-2

Time min:sec.	
1:00	Inside the furnace was filled with flame and smoke.
1:20	Joists started flaming.
13:30	Fire inside the furnace seen through the opening of the joint. (Subfloor burned through).
14:00	Along the edge of the joint, dehydration phenomena and black char appeared.
17:21	"Flame Through".

Test #S-3

1:10	Joists started to burn.
5:30	Smoke from joint.
12:15	The furnace fire appeared through the gap. (Subfloor burned through).
12:45	"Flame Through".

Test #S-4

1:00	Joist on fire
7:00	Gray smoke filtering through the carpet, and the center part of the unexposed surface was covered with moisture.
14:00	Fire reached underlayment. (Thermocouple indication)
21:00	Deflection due to the load was observed near center.
22:00	Black Char on the carpet started to be formed.
25:00	Load was relaxed. (Could not sustain the weights)
25:50	"Flame through".

Test #S-5

Time min:sec.	
1:00	Joist started to burn.
6:00	Exposed surface under thick flame.
9:00	Smoke was noticed around T and G joint near the north end. At the same time its color became charcoal black, and sagging and opening at this joint was observed.
9:30	The fire inside furnace was seen through the opening.
10:30	"Flame through at the joints. The locations of "flame through" and openings at joints are seen in Figure 19.

Test #S-6

1:00	Joist started to burn.
8:00	Gray smoke filtering through the carpet and moisture noted on the unexposed surface.
14:50	Black char on the carpet surface. An appreciable deflection was observed midway between dead center and north and south end.
18:15	"Flame through".

Test #S-7

1:06	Ignition of joist.
7:00	Smoke started to appear on unexposed surface.
8:00	The top surface became dark near north end.
9:25	"Flame through."

Test #S-8

Time min:sec.	
1:05	Joist ignited.
6:15	Appearance of gray smoke through the carpet at the middle of the joint.
17:00	Deflection occurring at center.
19:10	Formation of the char region near center of the carpet surface.
20:20	Deflection was severe.
24:00	"Flame through" near center.

Test #S-9

1:00	Ignition of joist.
4:00	Smoke was seen above tongue and groove joint.
6:00	Formation of dark char on the edge of the joint near center.
9:40	Flames were seen through the opening made on the joint.
11:35	"Flame through."

Test #S-10

1:00	Joist started to burn.
7:40	Char forming on the unexposed surface near north quarter area.
10:25	Fire inside furnace was seen through the opening made where the char was formed.
11:00	"Flame through."

Test #S-11

Time min:sec.	
1:03	Joist started to burn.
7:00	Gray smoke and moisture was observed on the unexposed surface near the center.
15:00	Black char forming. Deflection was noted.
18:00	Deflection severe. The charred region about three inches in diameter.
19:20	"Flame through."

Test #S-12

1:00	Joist on fire.
3:00	Dehydration phenomena was clear on the edge of the wood.
4:00	Droplets of moisture was formed on top of the unexposed surface.
10:30	Sagging was observed near north end where tongue was broken during construction.
11:00	The sagging resulted in a small opening.
12:00	Fire inside furnace was seen through the opening.
13:21	"Flame through" where the broken tongue existed.
14:10	"Flame through" at a normal joint near center.

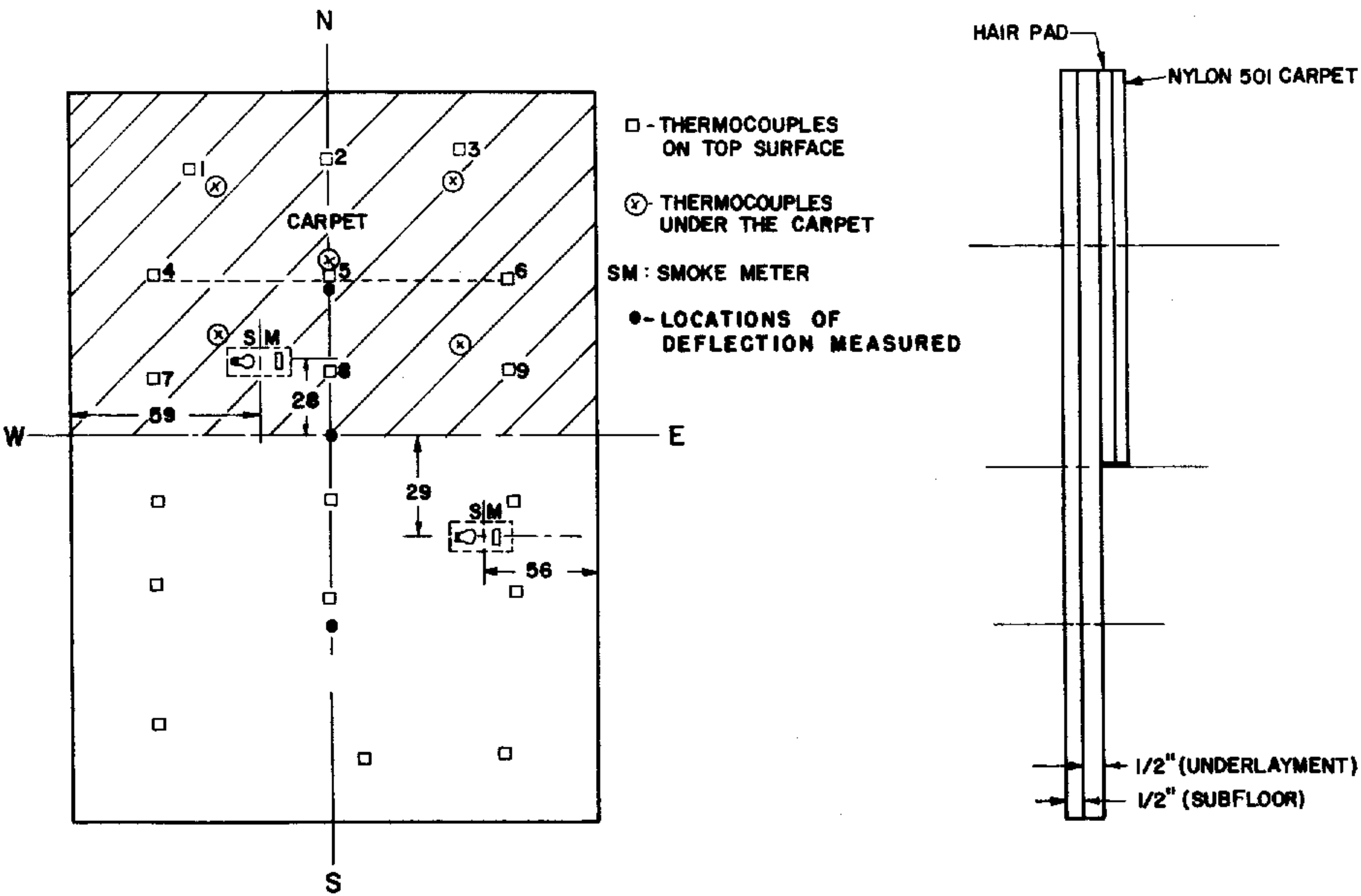

Fig. 1. Locations of Thermocouples and Smoke-Meters #L-1.

Fig. 2. Underside of the Floor Construction, #L-1.

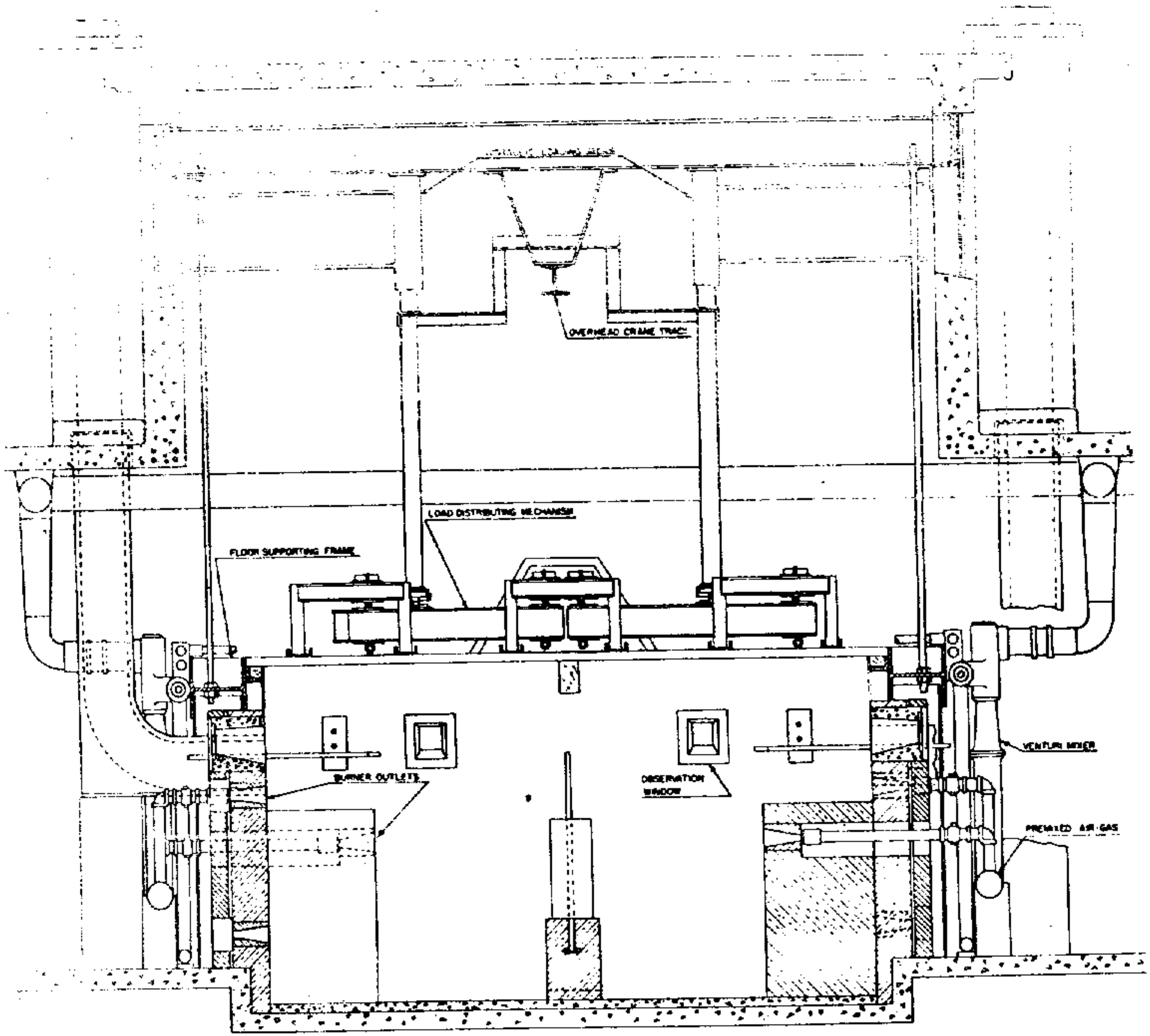

FIGURE 3. Section of the large floor-test furnace at NBS.

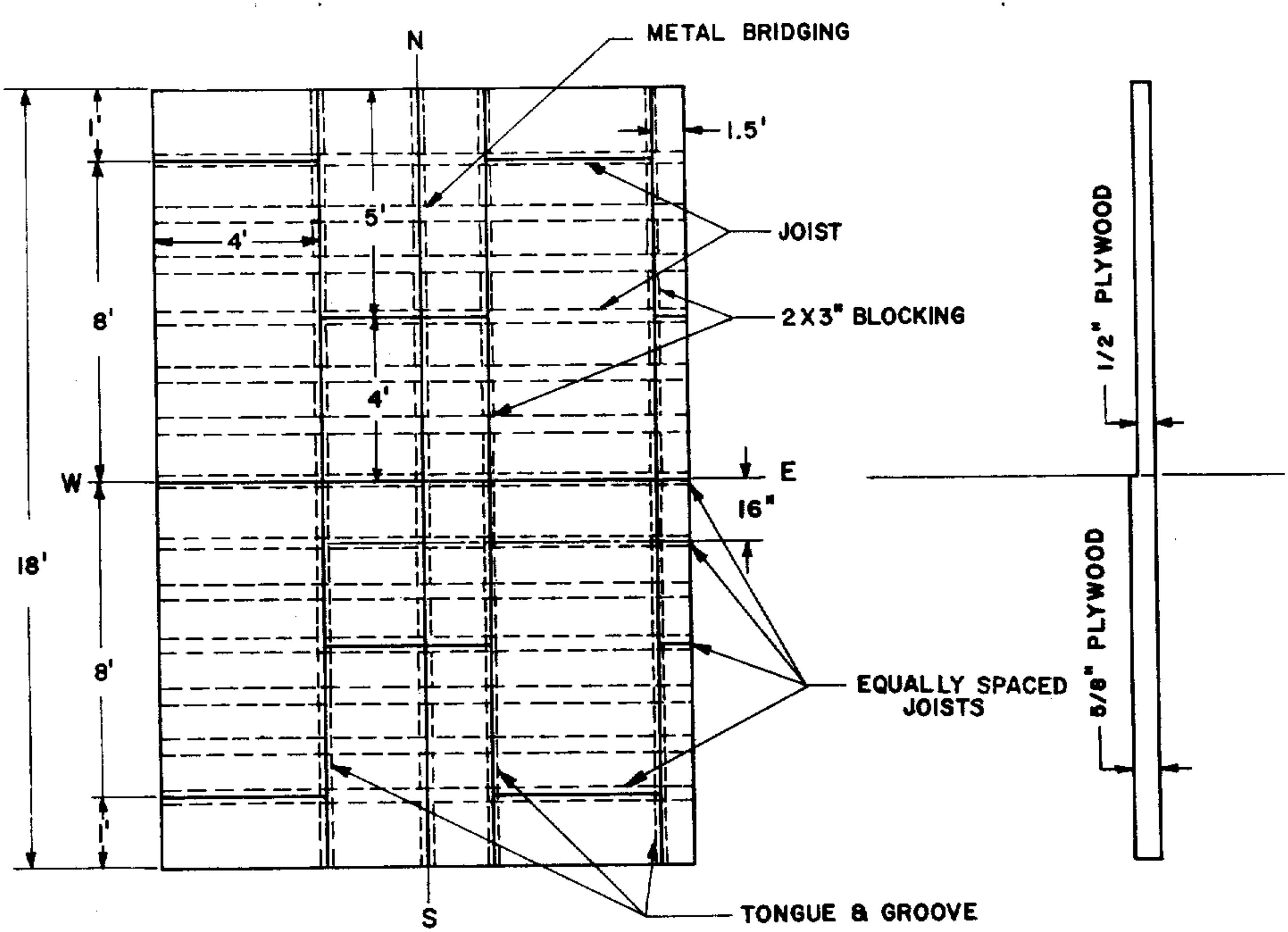

Figure 4. Floor specimen of Test #L-2

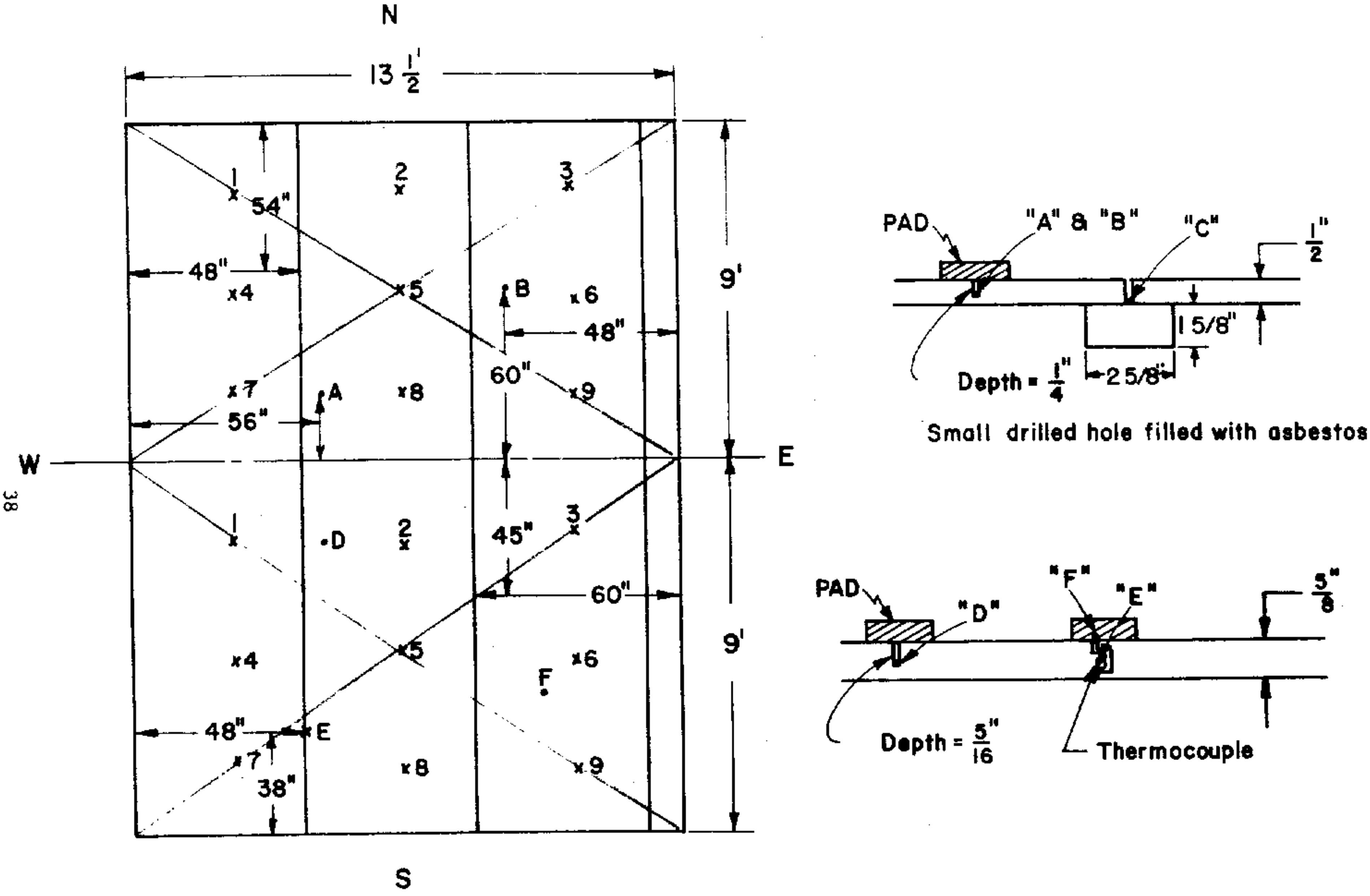

FIGURE 5. Locations of Thermocouples of Test #L-2

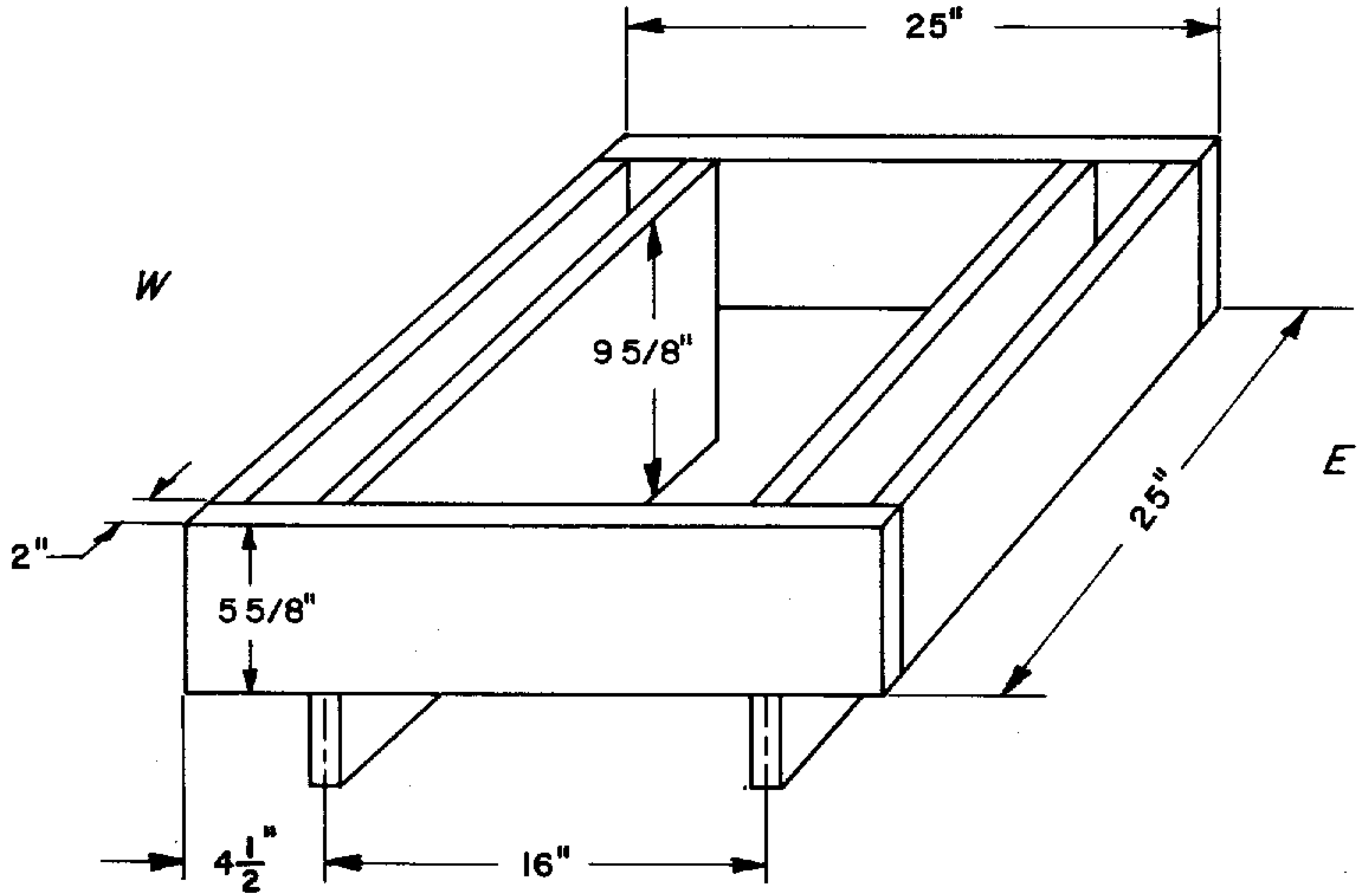

FIGURE 6. Framing for Small Scale Specimen

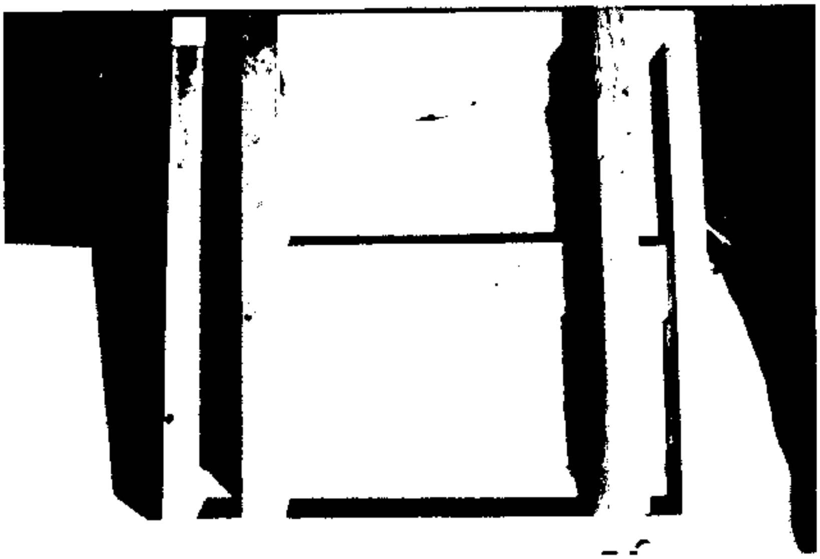

Figure 7 Underside of Specimen in Test #S-6

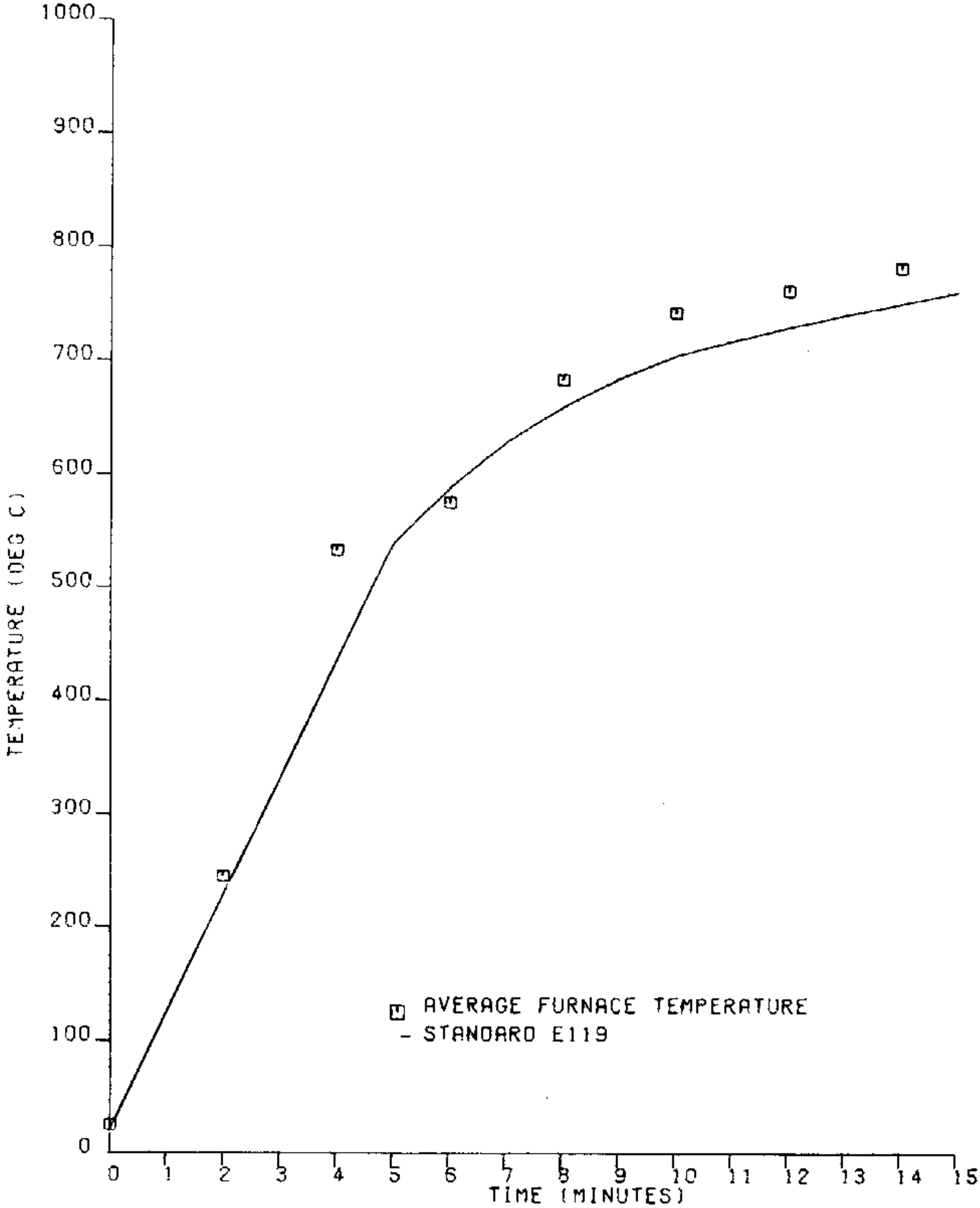

FIGURE 8. Average Furnace Temperature for #L-1 Compared with Standard E119

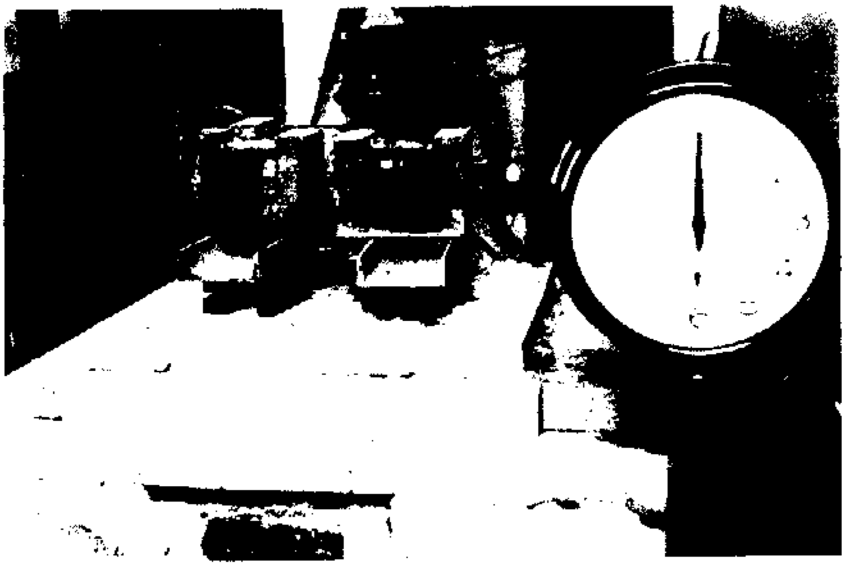

Figure 9 Location of Weights
Test #S-3

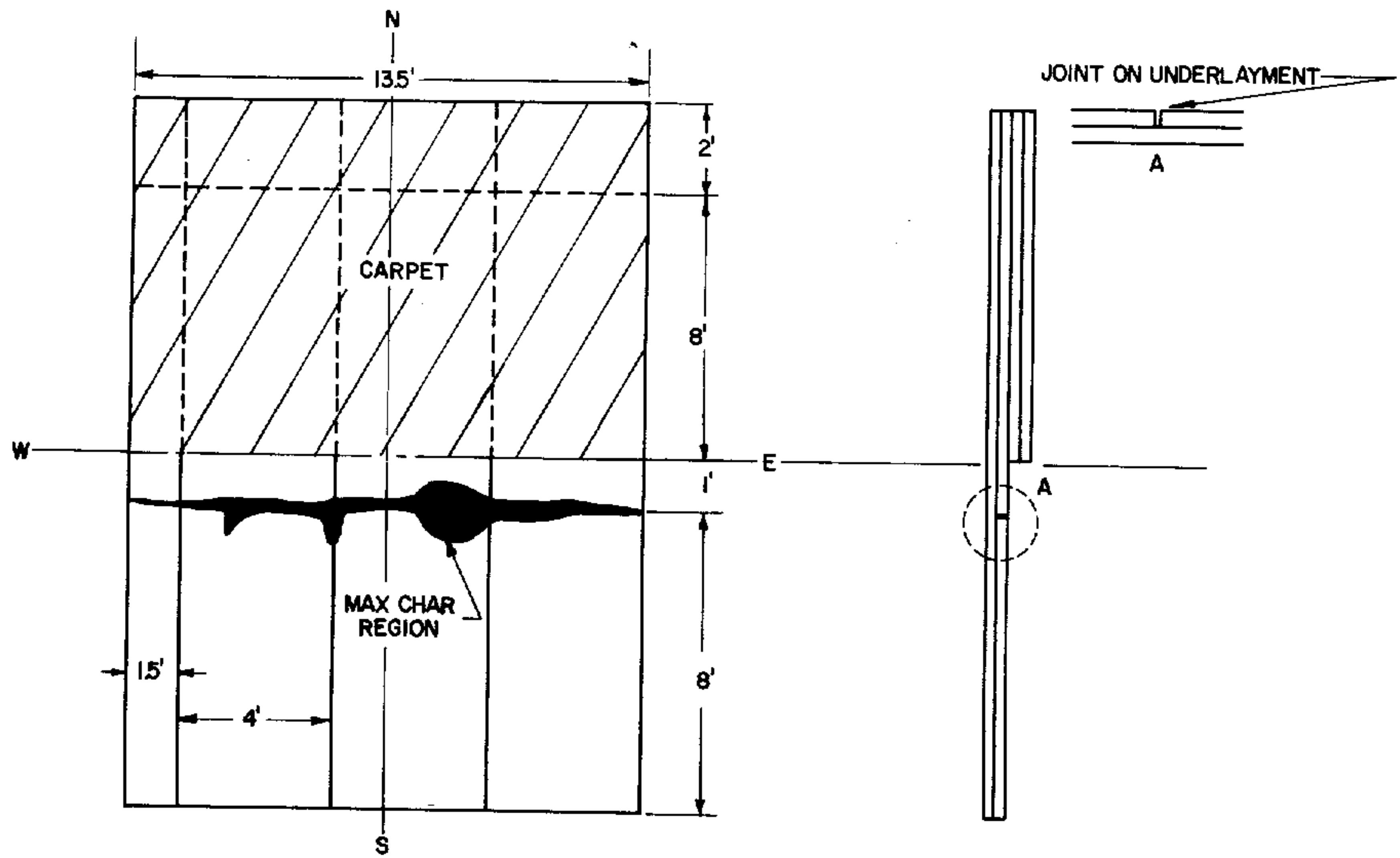

FIGURE 10. Char Region on Unexposed Surface after Test #L-1

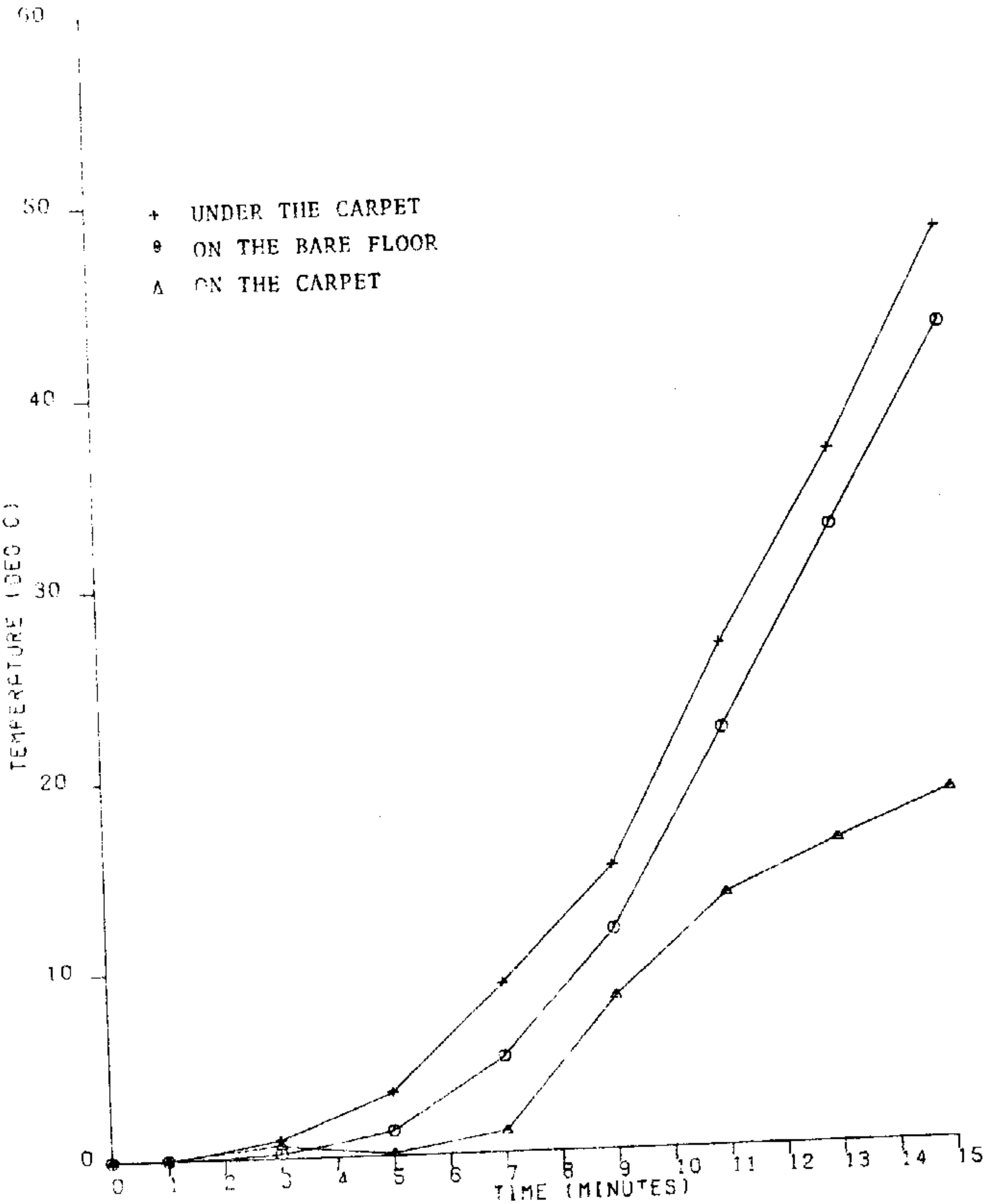

FIGURE 11. Average Surface Temperature Rises on Bare Plywood Floor, Under the Carpet, and on the Carpet (Test #L-1)

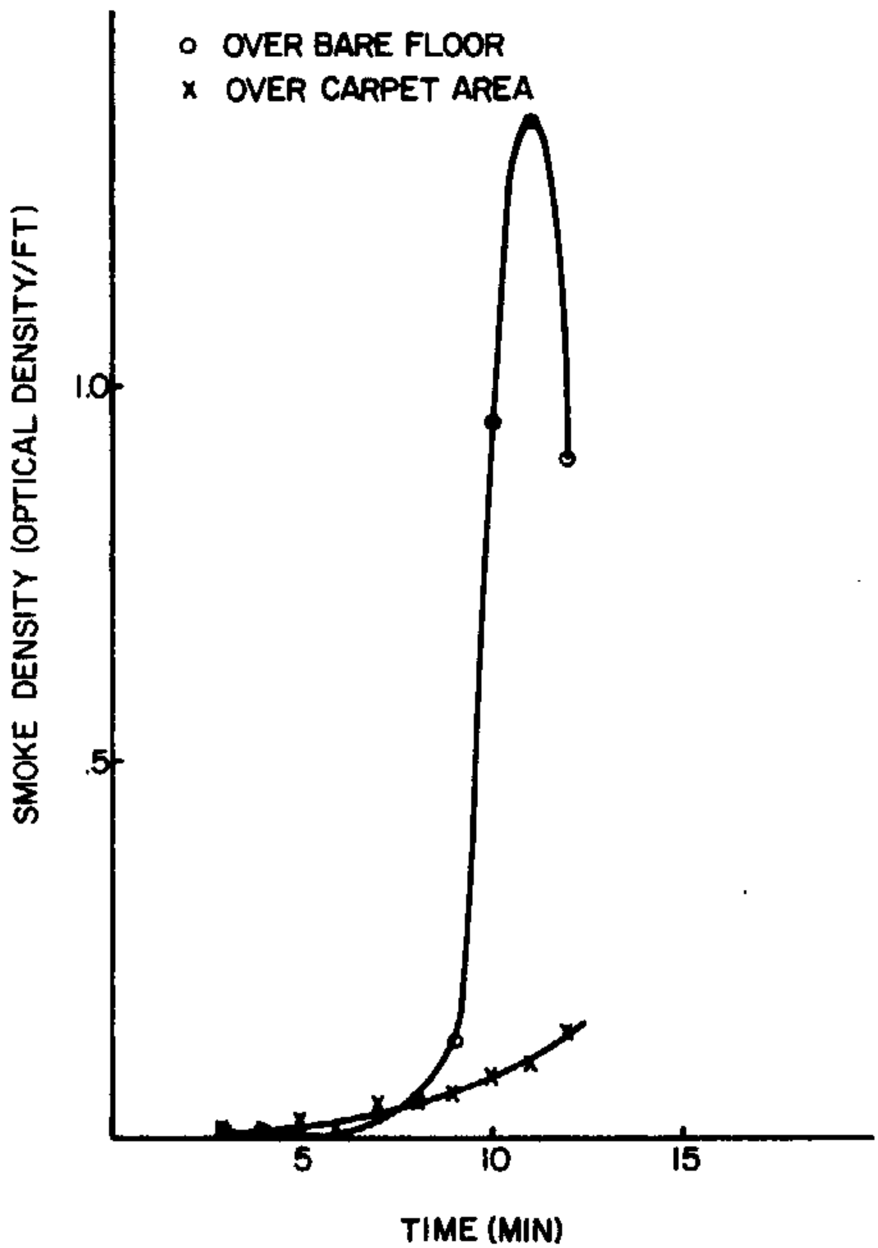

FIGURE 12. Smoke Density, Test #L-1

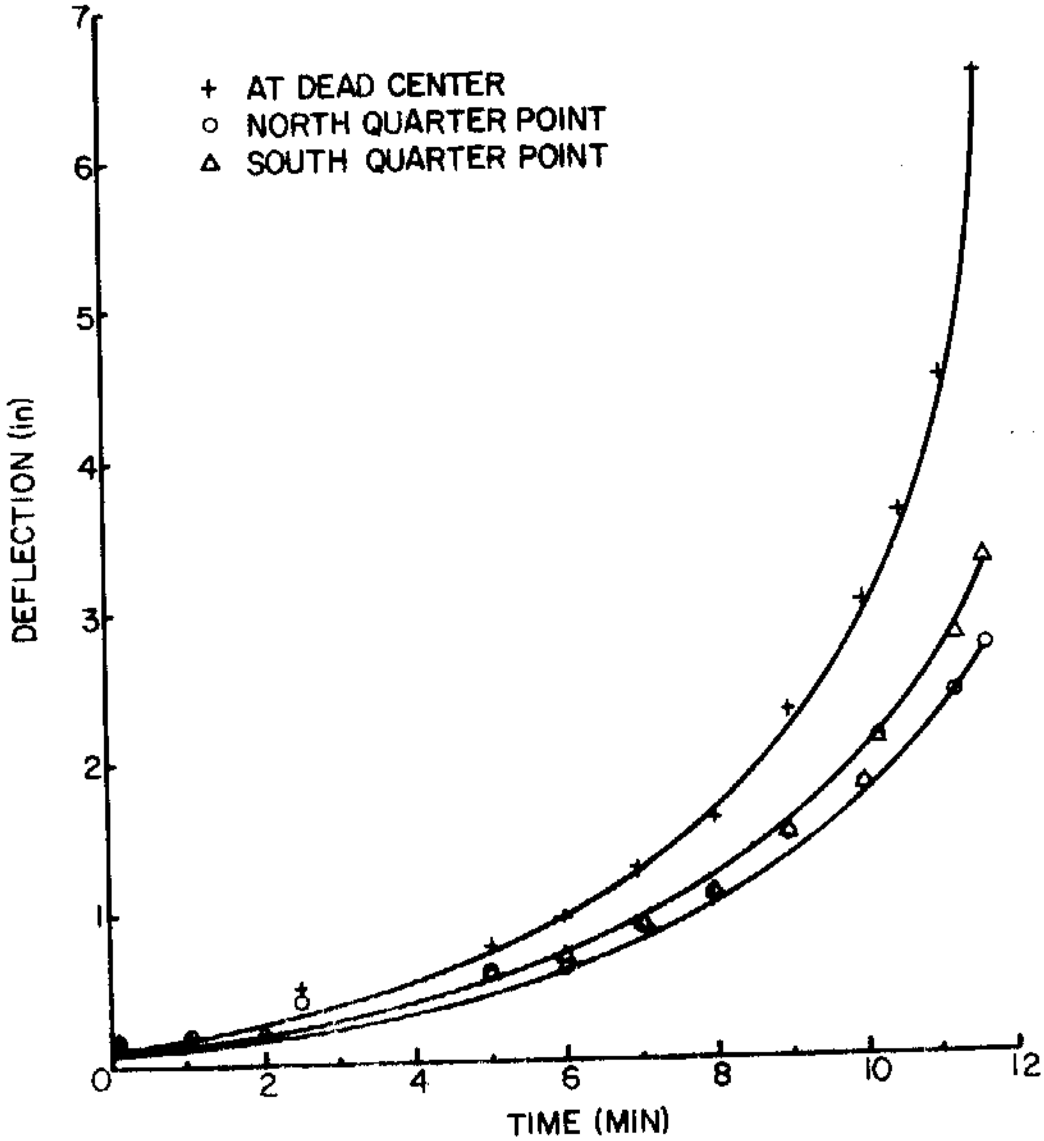

FIGURE 13. Deflection Measurements Test #L-1

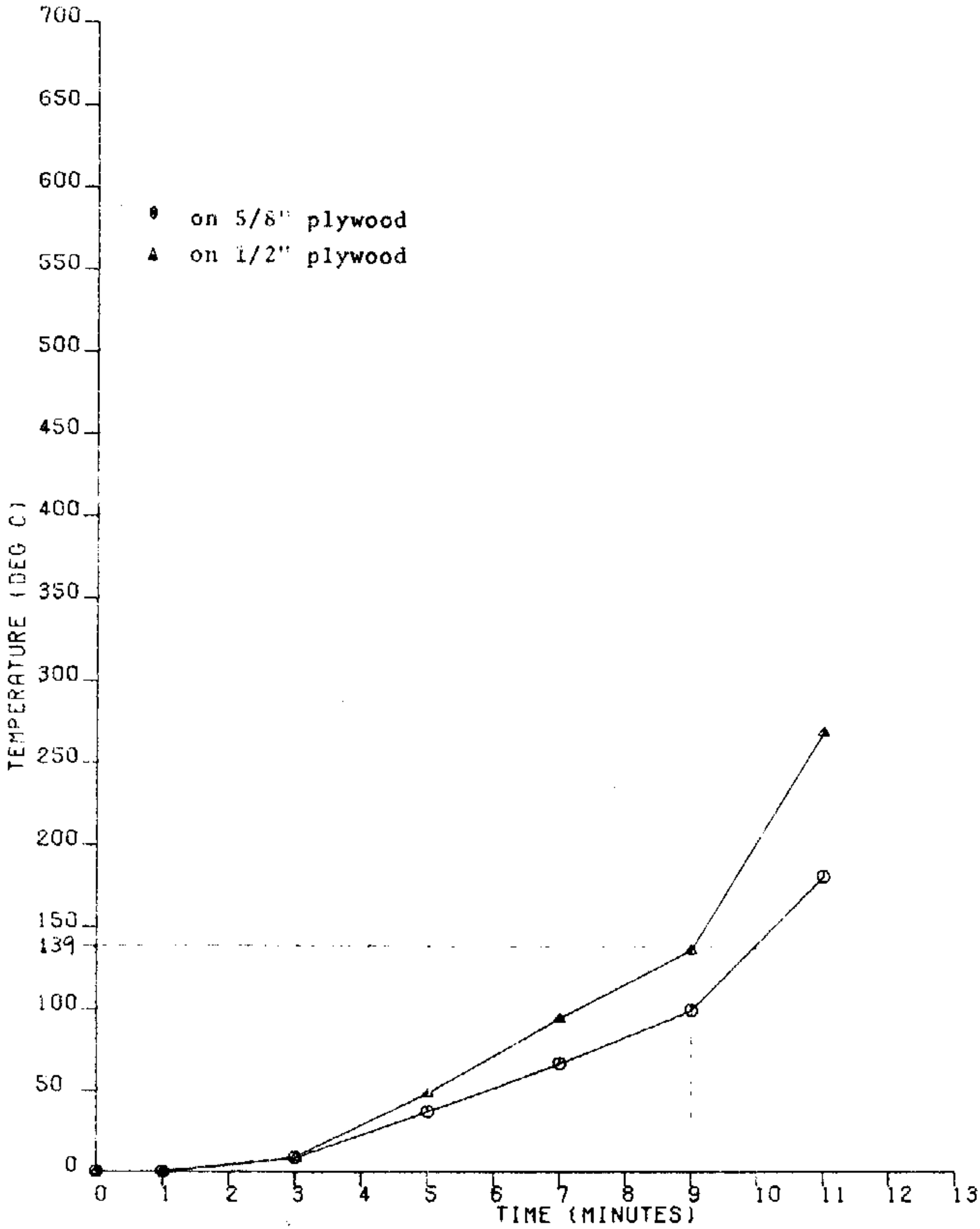

FIGURE 14. Average Temperature Rises for Test #L-2

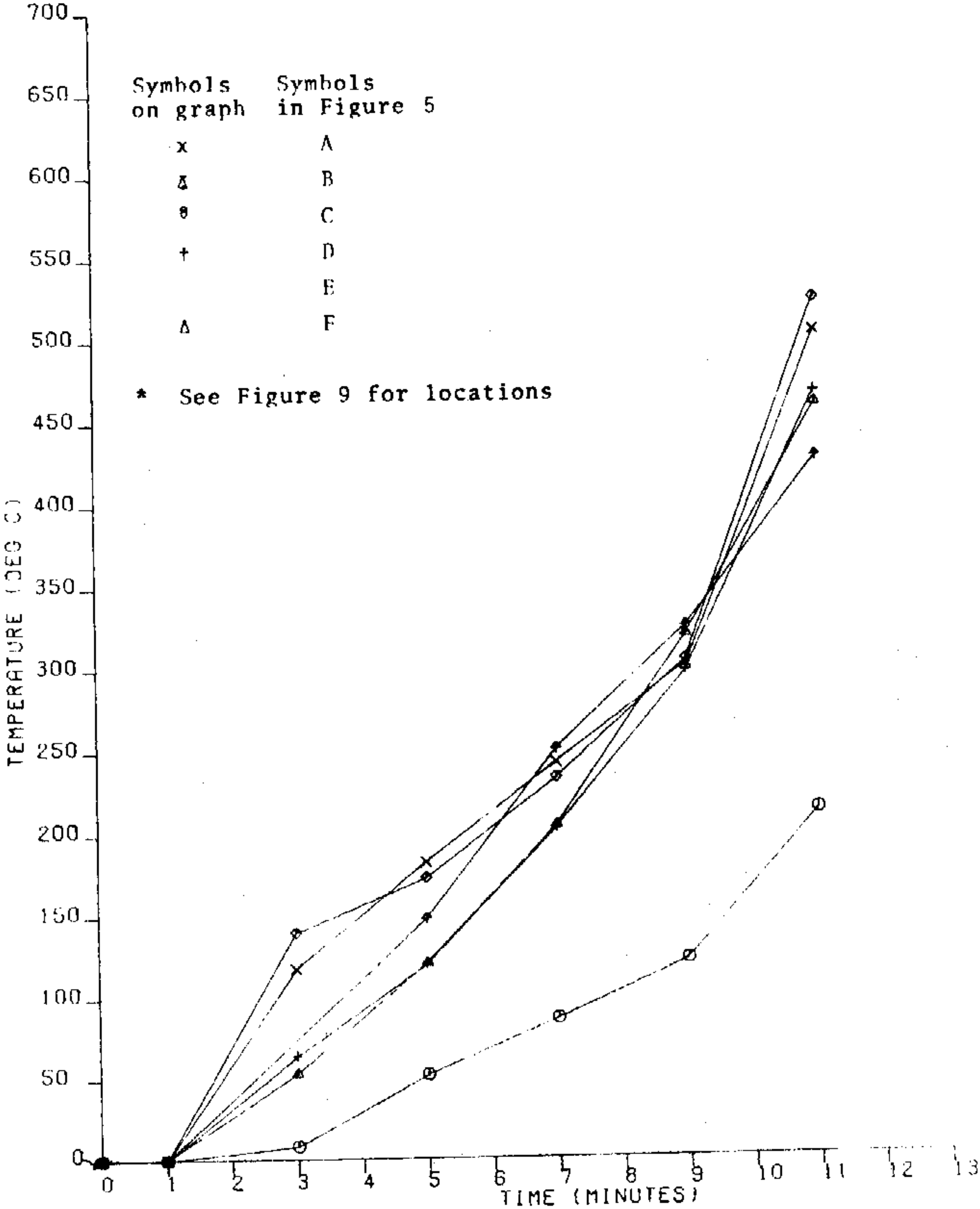

FIGURE 15. Temperature Rises of Special Thermocouples For Test #L-2

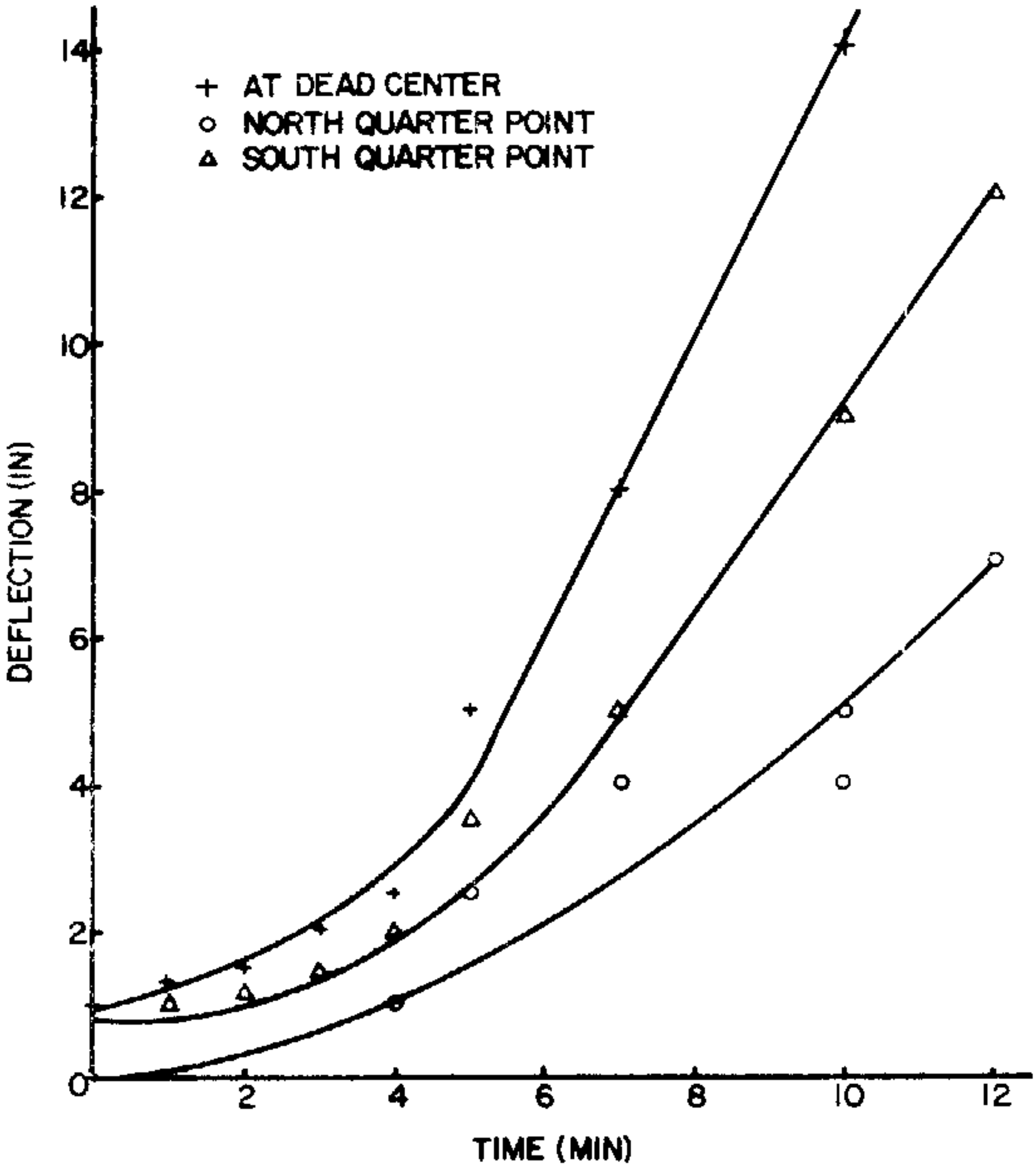

FIGURE 16. Deflection Measurements, Test #L-2

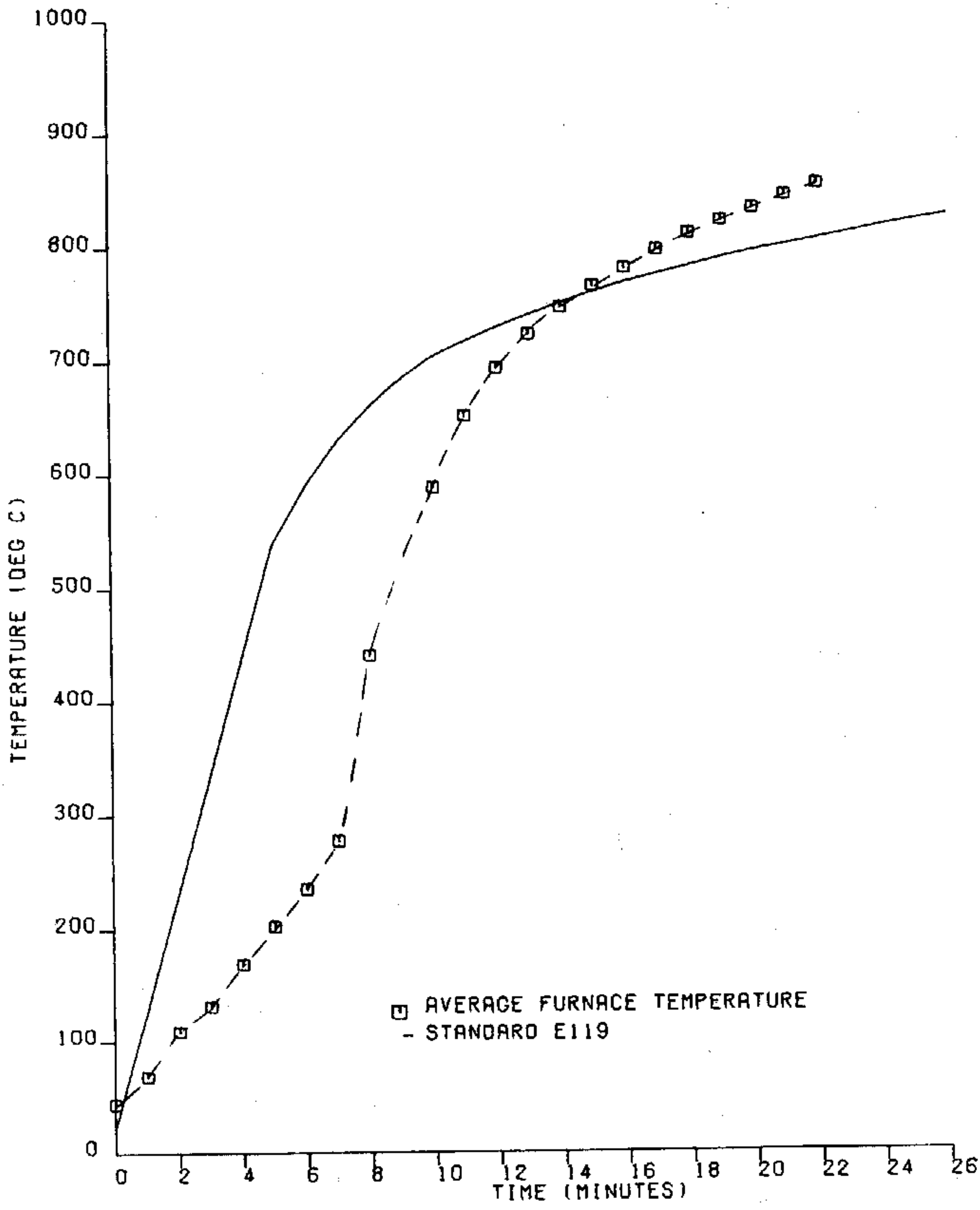

FIGURE 17. Average Furnace Temperatures for Test #S-1 Compared with Standard E 119

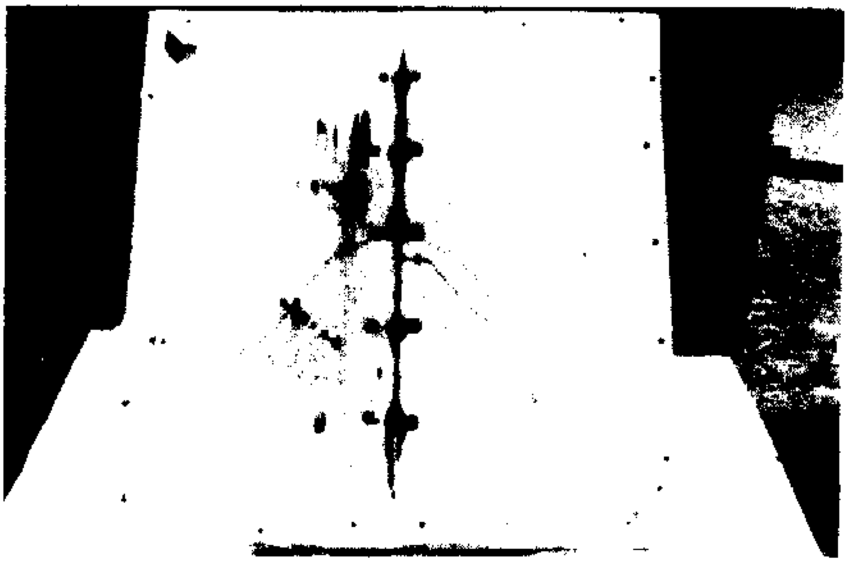

Fig. 18. Flame Through and Associated Char Region Test #S-3

Fig. 19. Locations of Flame Through Openings at Joint (after removing load) Test #S-5

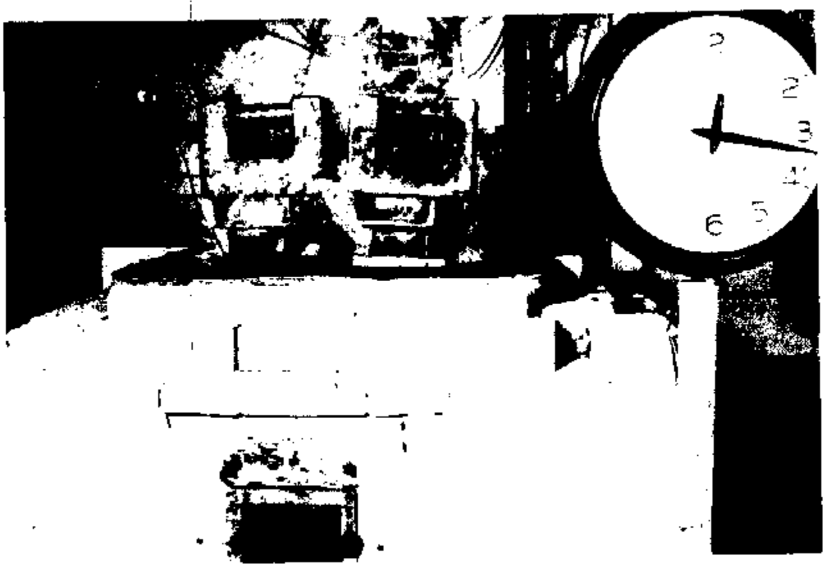

Fig. 20. Smoke at 17.5 min. Test #S-6

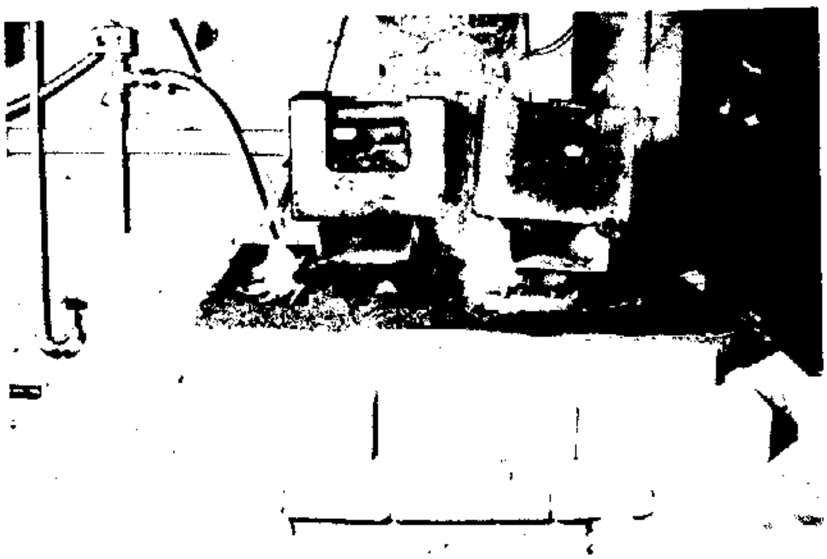

Fig. 21. Flame Through. Test #S-6

Fig. 22. Flaming Region Before Extinguishment. Text #S-6

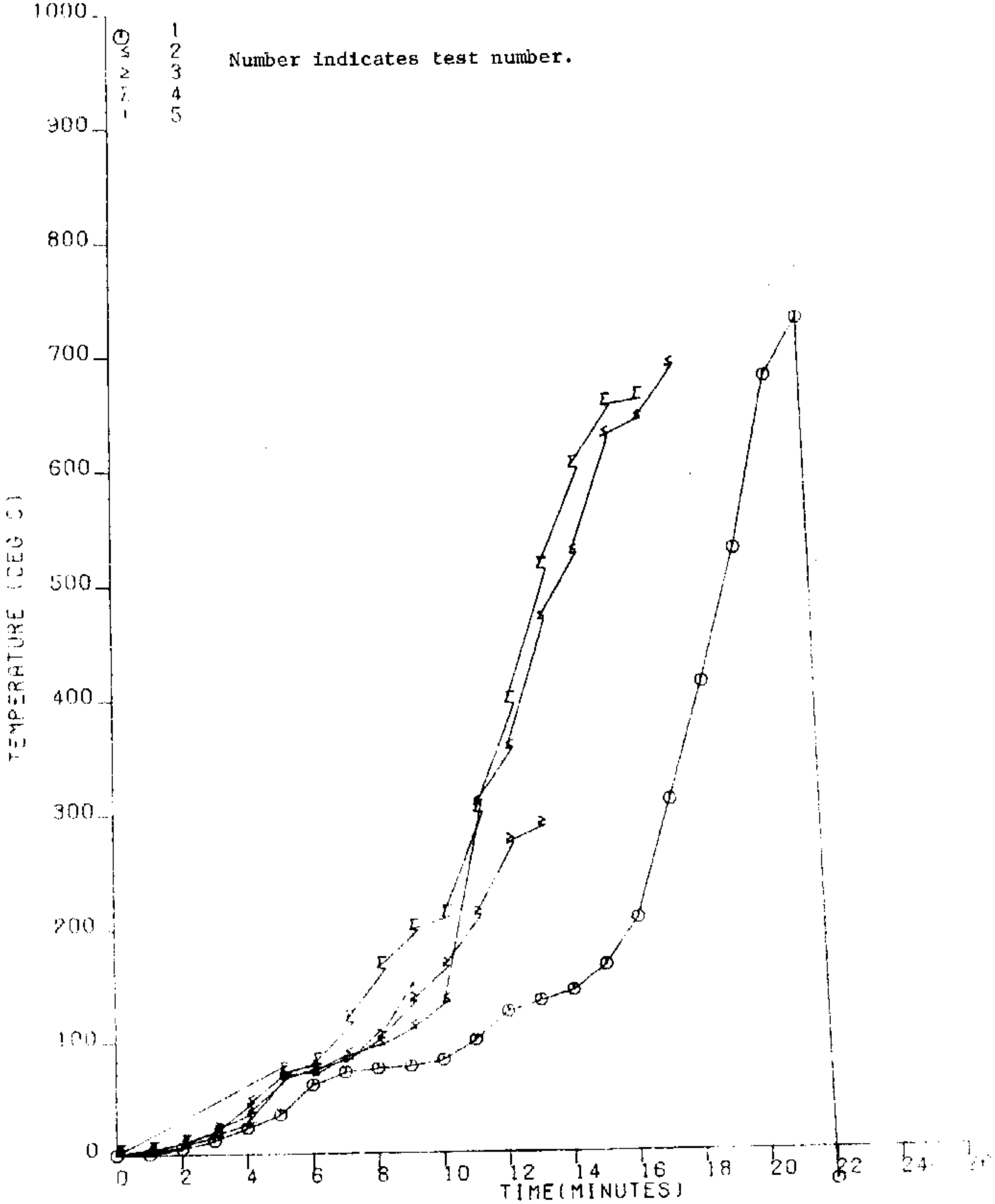

Fig. 23 Temperature Rises at Half Depth For 2X2 Tests #S-1 - 5

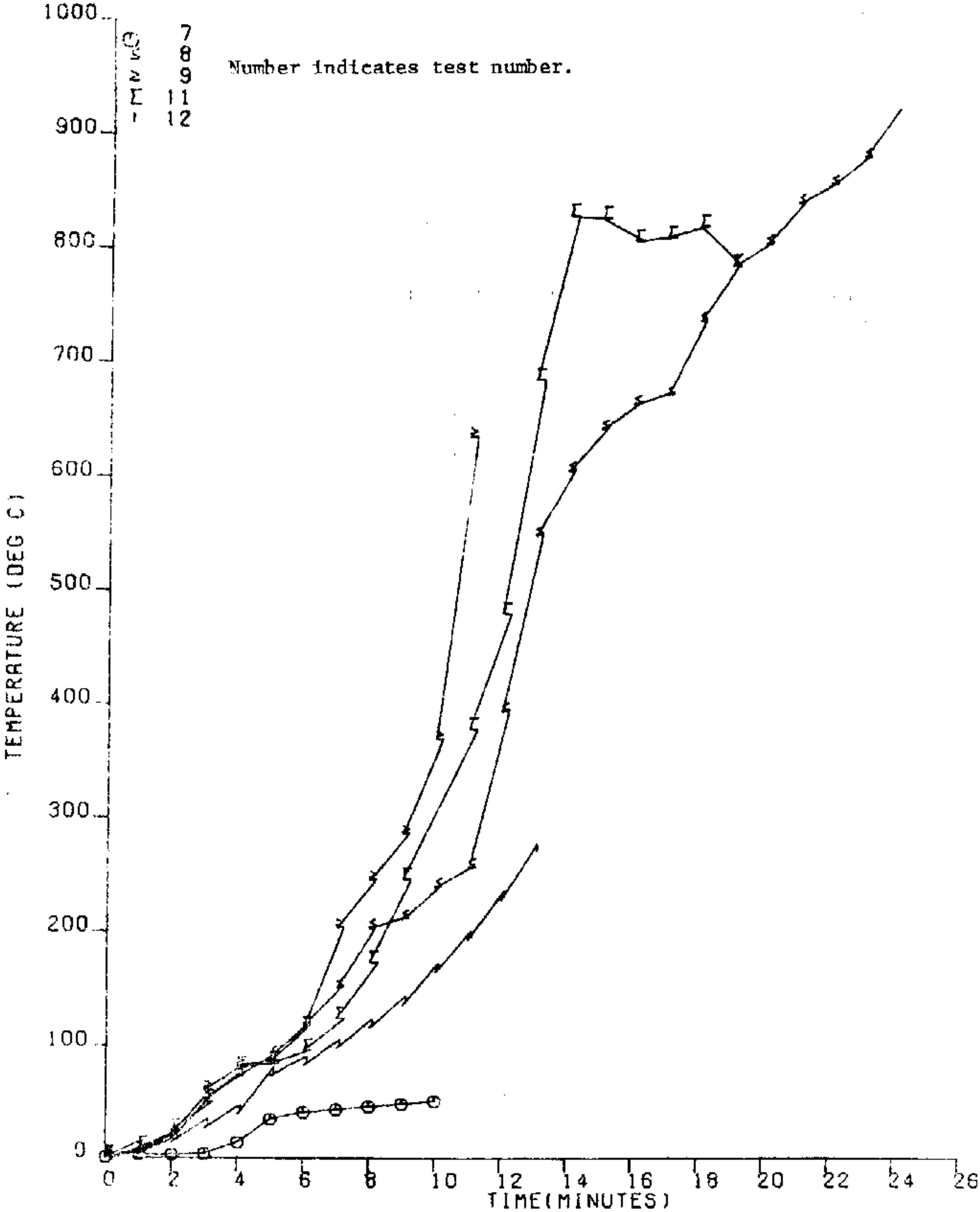

Fig. 24. Temperature Rises at Half Depth For 2X2 Tests #S-7 - 12

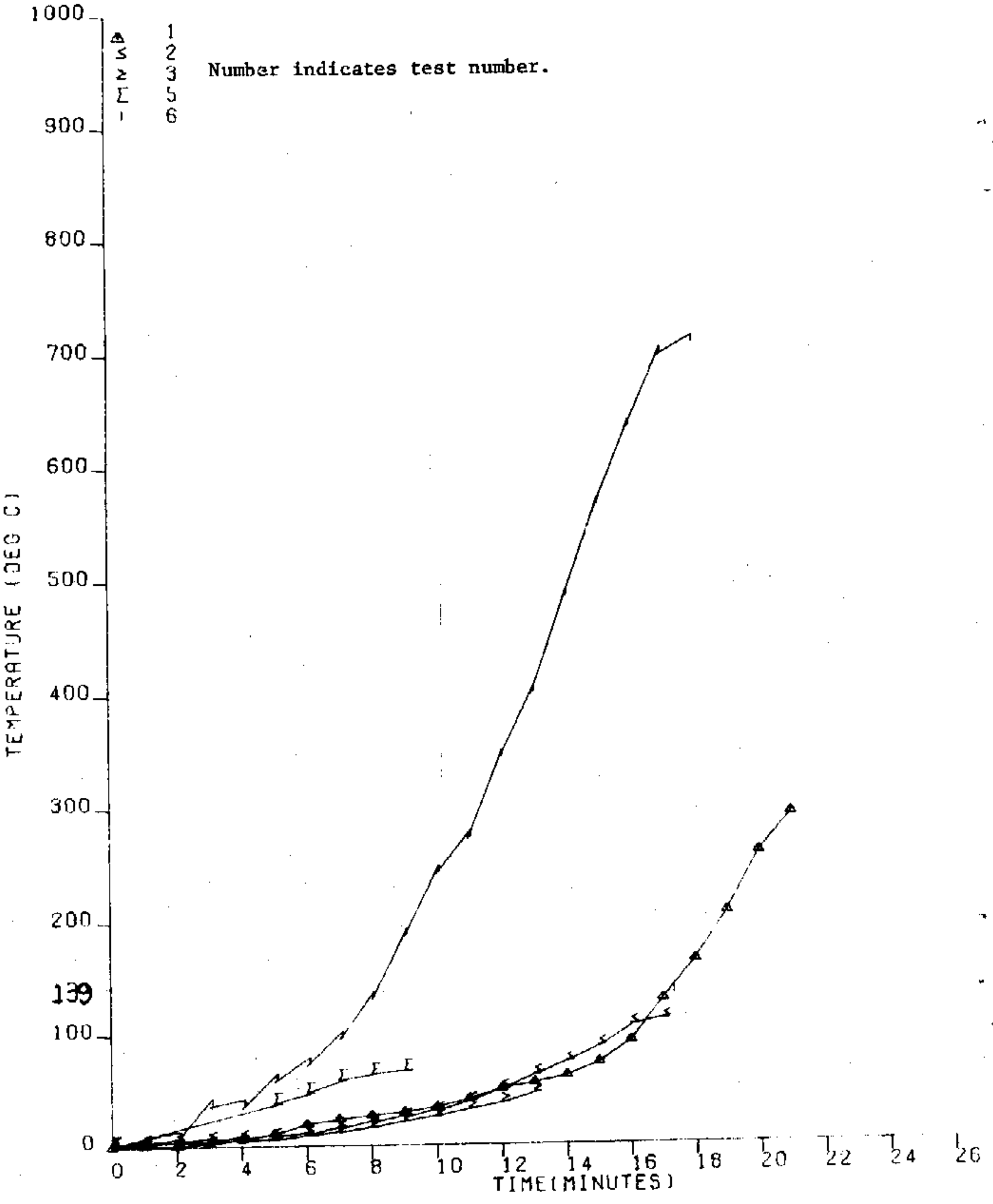

Fig. 25. Temperature Rises on the Bare Floor for Tests #S-1 - 6

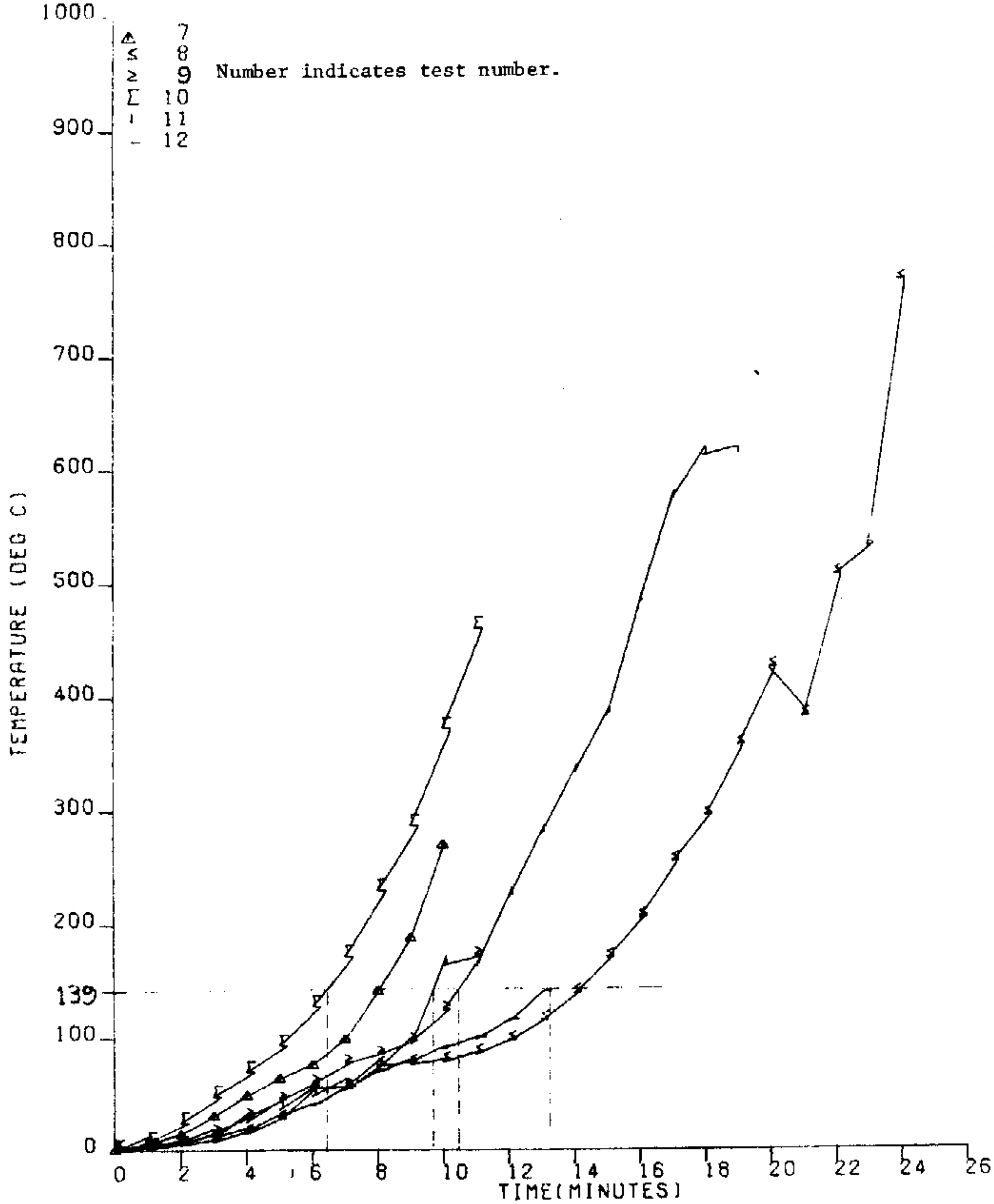

Fig. 26. Temperature Rises on the Bare Surface Under Carpet for Tests 7-12

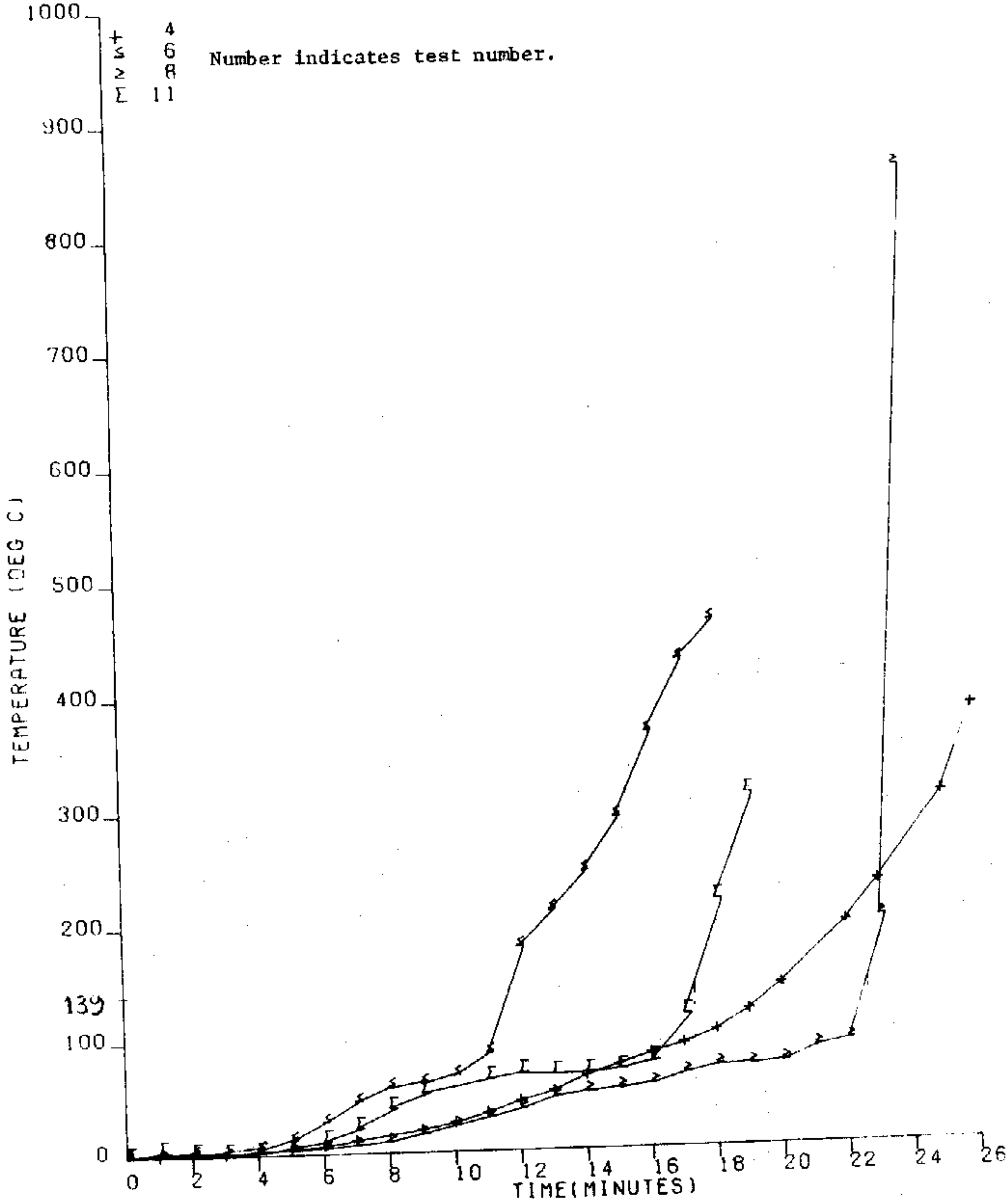

Fig. 27. Temperature Rises on the Carpet for the 2X2 Tests

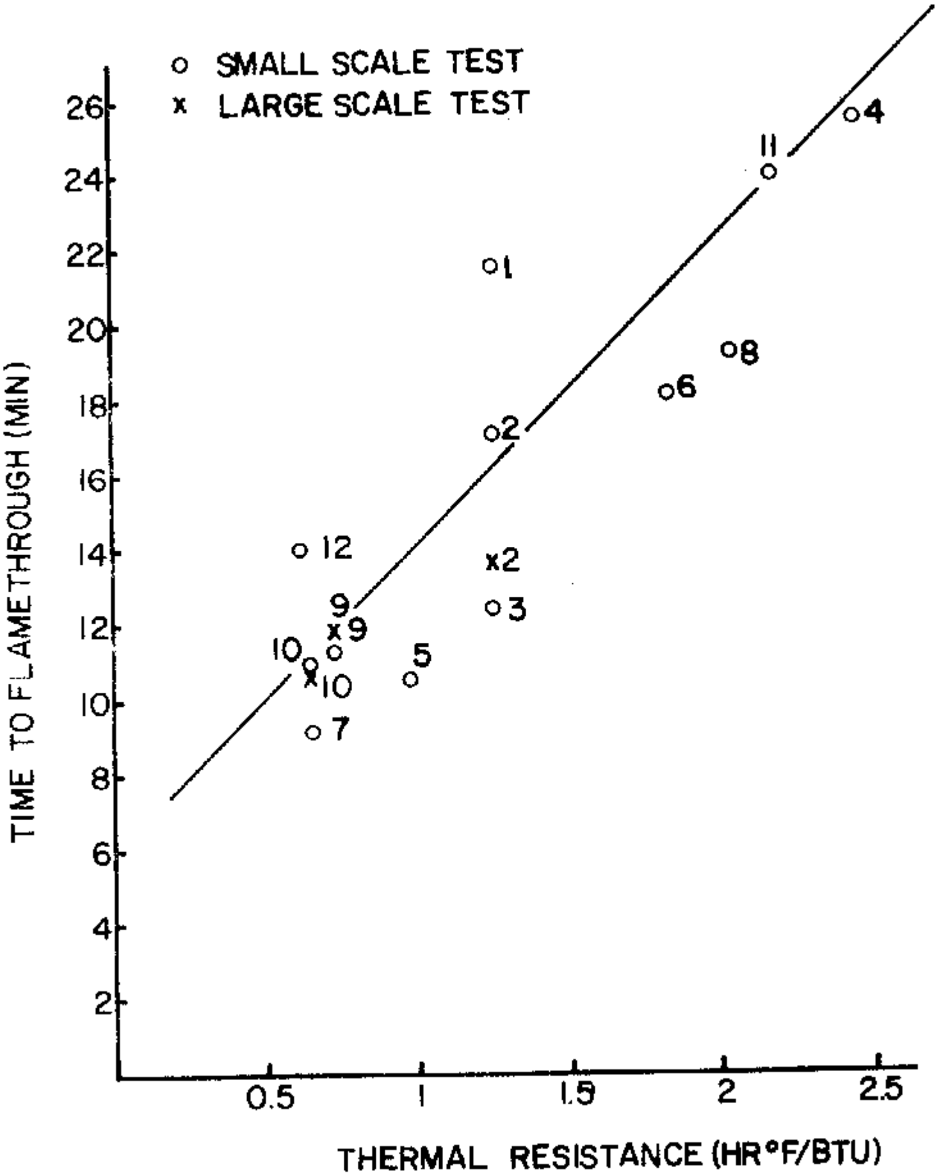

Fig 28 Thermal RESISTANCE of Floor Construction Vs Flamethrough Time

Appendix IV

SI Conversion Units

In view of present accepted practice in this country in this technological area, common US units of measurement have been used throughout this paper. In recognition of the position of the United States as a signatory to the General Conference on Weights and Measurements which gave official status to the metric SI system of units in 1960, we assist readers interested in making use of the coherent system of SI units by giving conversion factors applicable to US units used in this paper.

Length

1 in = 0.0254 meter

1 ft = 0.3048 meter

Mass

1 lb = 0.45 kilogram

Stress

1 psf = 47.88 newton/meter^2

1 psi = 0.332 newton/meter^2

1 plf = 13.49 newton/meter

Temperature

Temperature in °F = 9/5 (temperature in °C) + 32°F